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EVOLUTIONARY DEVELOPMENT OF AN
INTERACTIVE SCHEDULING SYSTEM FOR A
GENERALIZED FLOWSHOP

Research Report 80-13

by

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August, 1980

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The application of interactive computer techniques to the scheduling of industrial production operations has long seemed to be a potential way to break through the many problems that are encountered in this area, however, most attempts to apply such techniques have ended in failure. In this dissertation the author reports on a successful application created for an aircraft overhaul facility operated by the U.S. Navy. The major emphases of this dissertation are in the evolutionary method utilized for the development of the system and in the

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efforts applied during development to overcome the causes of failure in earlier interactive scheduling efforts.

The project involved the development of a Management Information System (MIS) to underly the later developments associated with the creation of production schedules. Subsequent to the completion of the prototype for the MIS, the next phase was the creation of a set of computer programs designed to create production schedules for future periods. The objective function applied during the creation of schedules involved the reduction of standard deviations for the daily requirements for critical manpower resources through the judicial selection of starting dates for the different aircraft being inducted for overhaul. This study evaluated the results for a number of different methods for the development of schedules.

The causes for failure of earlier efforts in the interactive scheduling area are discussed in Chapter 1. Chapter 2 contains a description of the production facilities, in general terms, for which the project results are applicable. The methods for, and development of, the computer programs and files are discussed in the third chapter, while Chapter 4 contains a description of the testing and analysis performed on the scheduling system that was developed. Chapter 5 draws conclusions as to the success of the system in its current application and then suggests possible future extensions for research and development in this area.

To

My Lovely Wife,

without whose encouragement

and support I would have failed,

and

My Mother,

who instilled in her pre-school age son

an interest in the application of

mathematics, probability, and statistics

to the problems of everyday life.

She taught me to play rummy, poker, and pinochle.

But how the subject-theme may gang,
Let time and chance determine;
Perhaps, it may turn out a Sang;
Perhaps, turn out a sermon.

--- Robert Burns ---
"Epistle to a Young Friend"

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EVOLUTIONARY DEVELOPMENT OF AN INTERACTIVE
SCHEDULING SYSTEM FOR A GENERALIZED FLOWSHOP

By

GERALD WAYNE MCDONALD

June, 1980

Chairman: Thom J. Hodgson
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The applicaton of interactive computer techniques to the scheduling of industrial production operations has long seemed to be a potential way to break through the many problems that are encountered in this area, however, most attempts to apply such techniques have ended in failure. In this dissertation the author reports on a successful application created for an aircraft overhaul facility operated by the U.S. Navy. The major emphases of this dissertation are in the evolutionary method utilized for the development of the system and in the efforts applied during development to overcome the causes of failure in earlier interactive scheduling efforts.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Interaction between man and machine appears to be an obviously effective technique for the development of production schedules for a generalized flowshop. In general, there exists a finite set of production resources available for use over a scheduling horizon to complete a given set of production tasks. One goal is to create a schedule which will allow the production facility to use these resources in an "efficient" manner while, at the same time, satisfying the inter-phase and completion dates for the tasks. This paper is to be concerned with the satisfaction of such a goal where the only variable available for modification is the sequencing and spacing of the starting times for the tasks, the resulting set of task starting times being called an induction schedule.

Conceptually, the role associated with the creation of such a schedule consists of two basic operations. The first is the creation of an initial schedule, constrained by the starting times assigned to tasks which have commenced prior to the beginning of schedule development. Second is the modification of a current schedule to account for unforeseen changes. Such changes might include, but not be restricted to, deletion of tasks assigned future starting dates, addition of newly assigned tasks, modification of the requirements for tasks currently in production, changes in the availability of resources, changes in task completion priorities, inter-phase times, or completion dates, advancement of the scheduling horizon as time passes, installation and

introduction of new processing equipment, development of new product lines, etc.

In the application of interactive computer techniques to these scheduling operations, one can envision taking advantage of the most effective talents of both man and machine, using each in the scheduling role for which they are best suited.

1.1.1 Description of a Completely Generalized Flowshop

When one uses the term flowshop the model typically visualized is that of Figure 1.1, where all of the tasks must pass through the same phases, in the same order, and tasks do not pass one another during processing.

A more generalized flowshop model is that shown in Figure 1.2. In this model a task may bypass one or more of the phases; i.e. require zero time and zero resources in a given phase, if you will.

A more complex flowshop model is that depicted in Figure 1.3, a completely generalized flowshop. Here one sees that it is also possible for a given task to be in more than one phase at a time, and as indicated by the upper, exterior path, tasks may pass during their processing. It is this more complex model with which this paper will deal; a model which may be associated with an industry involved in the construction of large, complex products in response to orders with specified completion dates. Examples of such industries might include those involved in the original construction, or the later overhaul, of products such as aircraft, ships, railroad engines, etc.

During each phase the tasks may call upon available resources such as floor space, electrical power, capital equipment, spare parts,

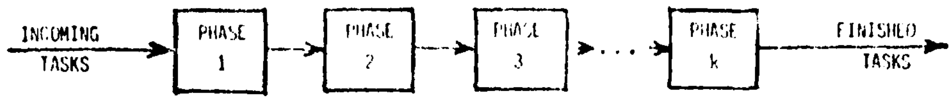

Figure 1.1 Normal FLOWSHOP Model

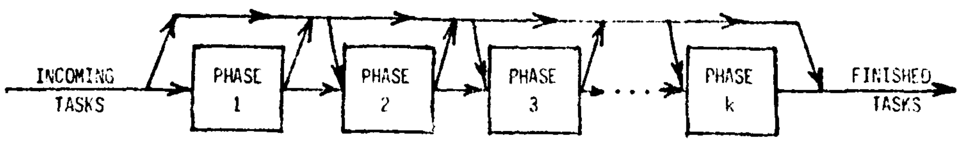

Figure 1.2 Generalized FLOWSHOP Model

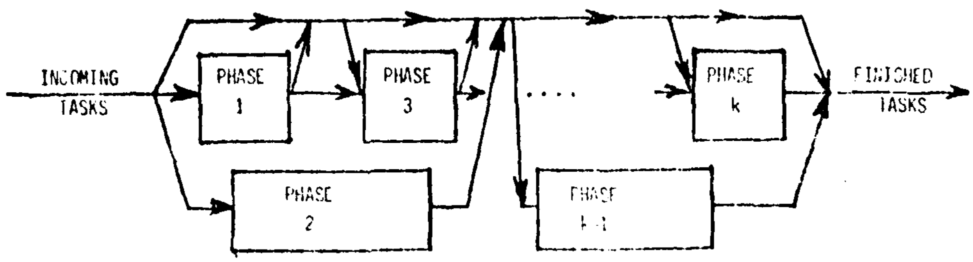

Figure 1.3 Completely Generalized FLOWSHOP Model

manhours from one or more selected sets of workers, etc. In addition, these resources may be required in more than one phase by a given task.

A feasible schedule for such a system is a sequence of starting times for the given tasks which allows their completion on schedule while, at the same time, it never requires more of any resource at a given time than is available at that time. It should be noted that there is no guarantee that a feasible schedule exists for a fixed set of tasks, completion dates, resource constraints, and planning horizon. Determination of feasibility is one small aspect of the first operation in the development of a schedule. When no feasible schedule exists, a computer and a human could work in consonance deciding which of the tasks are to be deleted, or which, and by how much, resource constraints might be relaxed. It is in this simple context that one can begin to evolve an interactive production scheduling system.

1.1.2 Underlying Data Base Requirements

Unstated, or often glossed-over at best, in many of the articles published on the subject of production scheduling is the fact that a complex data base system must be available on the computer before one can begin to create a computerized system for the development of production schedules. Associated with that data base must be a capability to predict resource requirements per unit of time given an induction schedule.

In the case where past schedule development has been accomplished by a human, aided by no more than a desk calculator and a sixth sense, it is highly likely that numerous simplifying assumptions

have been applied in order to make the problem of schedule development more tractable. Such assumptions may include: reduction of the number of different constraints, selection of a larger time unit for the measurement of resource availability and requirements, and restriction of the tasks allowed in order to provide sufficient slack in the schedule to preclude disastrous effects from unforeseen circumstances.

When the time comes to automate the scheduling operations there is often a tendency to retain many of the tractibility assumptions. Following such a direction may well lead to the development of a management information system (MIS) that will fail when it is ultimately asked the following two questions:

(a) What are the requirements for resource X given the current schedule, and

(b) What will be the impact on resource X requirements if the schedule is changed to ......?

Hence, during the creation of the MIS to underly a production scheduling system one must evaluate every assumption and retain as few as practicable in order to provide as flexible an MIS as possible, and to retain the user's confidence in the final system. This subject will be discussed in detail later.

1.2 Related Literature

Victor Godin, writing in an article surveying the state of the art in interactive scheduling [8], dates the beginning of interactive *scheduling efforts with the publication in* 1960 *of a* paper by J.C.R. Licklider entitled "Man-Computer Symbiosis" [20]. The statement by Godin that "The age of interactive man-computer problem-solving systems commenced with Licklider's paper . . ." could possibly be

considered as having overlooked earlier man-machine problem-solving efforts. For example, the mechanical Mark I aiming system for the large shipboard guns of World War II was the marvel of its day.

Following Licklider's paper, and expansions thereon by others, interactive systems have become widely used in many areas, but little has been done in their application to the problem of scheduling, and in particular in the area of flowshop scheduling. In fact, the professional journals are nearly devoid of papers on this particular subject. A near majority of the related work applies to job shop or project scheduling applications.

The earliest historical record of interactive scheduling was the work of Ferguson and Jones [7] associated with a six machine job shop. (In a job shop the phase sequence may vary from task to task.) Their objective at the time was " . . . the enrichment of (the) participants' understanding of the scheduling process and the man-computer program interaction possibilities."

From 1966 thru 1967 the Stanford Research Institute worked on an interactive job shop scheduling system for N.V. Phillips, a large firm in the Netherlands. This system made extensive use of graphical displays of job shop status and performance, and may have been the most expensive and powerful interactive scheduling system ever developed. Little information is available to the public at this time on the SRI-Phillips system. Work on the project was discontinued in 1971 due to prohibitive graphic display costs. Some discussion of this system is available in [15], [26], and [27].

The first operational, interactive scheduling system in the U.S. was developed by Godin and Jones during 1969 for use by the Western

Electric Corporation in their North Andover, Massachusetts motor winding plant. The system utilized an IBM 360/65 computer without time-sharing facilities. The system console was used about one hour per day as the man-machine interface to provide interaction. After running less than a year the system was discontinued, ostensibly due to the awkward interface [9] [10].

Others also worked during the sixties on various facets and aspects of interactive, job shop scheduling problems. Some of the aspects studied include: comparison of the number of schedules considered by a man-machine team versus the number considered by a human team [19], efficiency of interactive versus batch scheduling [14], different hardwares for input, output, and display [1], simulation modeling taking advantage of a deterministic 'look ahead' [26], and human monitoring of the computers progress during a heuristic development of a schedule [17] [18]. This last system, developed by Holloway and Nelson, is noteworthly because it allowed the machine to churn through vast numbers of computations and then call on the human partner when it needed help.

In the early seventies a number of people worked on interactive scheduling problems. Notable among them was the work of Connor in developing a system called PROSPAC, short for Production Scheduling, Planning and Control. Connor has since developed a commercial version of this job shop scheduling system called PRODUCE, which reportedly has few customers [4].

Another noteworthy effort was that of Weist in developing a "Scheduling Program for Allocation of Resources," SPAR for short [28]. This work was done in connection with the interactive scheduling of a

project, rather than in the job shop arena of the scheduling systems discussed above.

Others working on the optimization of project scheduling during the early seventies include: Davis and Heidorn [6], Pritsker, Waters and Wolfe [25], and Herroelen [16].

The majority of interactive efforts, if not all, have fallen into these two classes, job shop and project. Except for the work on network scheduling of projects, most of the scheduling attempts have been on small or medium-sized systems; or else they have been done in computer batch processing mode. Many of the batch-mode solutions have involved Zero-One linear programming techniques [24] [25].

1.3 Shortcomings of Earlier Systems

In spite of the activities described above, the future capabilities envisioned by Licklider and his successors have not come to fruition. In his survey article [8], Godin suggested eight hypotheses for this failure. Evalutation of these reasons provides numerous ideas regarding potential areas for research in the development of on-line, interactive scheduling systems for job and flowshop systems. The following is a condensed and paraphrased list of Godin's hypotheses:

(a) The excessive assumptions underlying past systems have often rendered their results unacceptable.

(b) A lack of flexibility and sophistication has made past systems difficult to modify and adapt to rapidly changing environments.

(c) Interactive computer systems have not been readily available to many schedulers.

(d) Many Operations Managers have been unfamiliar with computer based systems and reluctant to use them

(e) Computer hardware, software, and graphics to support interactive scheduling have been prohibitively expensive.

(f) Interactive scheduling systems have been commercially unattractive due to:
   (1) Custom design of individual systems,
   (2) Cost of training potential users,
   (3) Difficult evaluation of cost savings attributable to improved schedules, and
   (4) Difficulty in convincing potential purchasers within a firm of the attractiveness of the system.

(g) Implications of bad schedules often go unrecognized because schedulers have built in slack to protect from the disaster of a failed schedule.

(h) Political pressures within a firm often override important scheduling decisions and criteria, sometimes unknowingly.

The concepts contained in this list have provided a valuable foundation for the development of the interactive scheduling system described in subsequent chapters. At almost every corner where a decision had to be made, reference to these hypotheses provided sound guidelines and direction.

Certain recent changes in education, technology, and computer costs have helped to overcome the negative impact of some of the difficulites hypothesized above. For example:

(a) Computer hardware and interactive systems have been greatly improved and their costs have been markedly reduced. In particular the advent of mini and micro-processors has placed interactive systems in the hands of a large number of prospective users.

(b) Concurrent with this hands-on experience has been an increase in the computer education of potential users with a corresponding reduction in their reluctance to use computer based systems.

(c) Great strides have been made in the handling of data bases for unstructured decision problems such as scheduling. One example of this is the Decision Support System (SDS) fostered by both the Sloan and Wharton Schools of Management [2].

(d) The evolution of interactive scheduling systems has proceeded onward, albeit slowly. For examples one can look to the SPAR system of Weist, and more recently to the concepts outlined by Per-Olof Carlson in his 1977 master's thesis [3].

1.4 Overview of the Dissertation

The following chapters describe the evolutionary design, development, and implementation of an interactive computer scheduling system for a completely generalized flowshop facility, namely a large-scale, aircraft overhaul plant operated by the U.S. Navy. Following a description of the overhaul plant and the products, including their associated resource requirements, and the constraints thereon, is a discussion of the development of a management information system to underly the later design and development of interactive scheduling programs. Subsequent chapters will describe the methods and computer programs used to develop initial proposed schedules interactively and then to make improvements on one or more of those schedules with a view toward leveling the requirements per unit of time of certain individual, or combinations of individual, critical resources. Finally, there is a description of the heuristics used to search for improved schedules.

Emphasis throughout the following chapters is placed on describing the evolutionary development of this system in an environment that provided two-way feedback between users and the developer and swift implementation of that feedback into emerging versions of the system. Additional highlights will call attention to the details, associated with the hypotheses concerning failure enumerated in section 1.3 above, which were considered manadatory to ensure a reasonable chance of success for these efforts.

CHAPTER 2

DESCRIPTION OF THE PRODUCT SYSTEM

2.1 Description of Product Types

2.1.1. Standard Products

The naval aircraft rework facility for which this interactive scheduling system has been developed performs both major overhauls and repairs on aircraft and aircraft components. In order to allow for the complete development and implementation of a scheduling system in the time frame allowed by a dissertation, the system developed was limited to that of creating and improving only schedules for the overhaul and repair of aircraft. However, one criteria for the system developed was that it be easily adaptable to scheduling overhauls of aircraft engines in the near future.

Considering only aircraft overhauls, the number of different "standard" products in the system at any time averages about ten. Approximately eight other product types are required sufficiently often to encourage their inclusion in the scheduling programs as standard products. By the term standard in this instance one refers to a type of aircraft overhaul that can be accomplished in the normally alloted time frame for that type, and can be completed within a set of manhour requirement standards, from each of the various production shops, that have been historically developed for that type of aircraft overhaul.

Immediately upon induction into the overhaul program, each aircraft goes through a phase involving estimation and evaluation by an

inspection and planning team to develop an initial determination as to the capability of completing that particular aircraft as a standard product. In addition, each aircraft goes through a more thorough inspection after the paint has been removed to again determine whether it is a "standard" product. For scheduling purposes in this system, any product that passes both inspections as a standard type can be considered to have an overhaul that is deterministic with respect to time and resource requirements. Any aircraft that is determined to be nonstandard as a result of these inspections is then assigned a revised overhaul program. A new, deterministic set of manhour and time requirement standards is immediately developed and assigned to these "nonstandard" types.

Based upon historical data on the number of standard and nonstandard types of overhauls for aircraft, the decision was made to develop a system that allowed for a total of thirty-two separate product types. This number is also sufficiently large to allow adaptation of the system to engines at this facility, albeit both aircraft and engines will require separate and distinct systems due to the disparate nature of these product groups.

The standard aircraft types are also grouped into what have been designated "macro" groups. All of the standard aircraft within each group require the same production phases, in the same sequence, and all require the same amount of time in the respective phases. From a scheduling point of view, the only difference between types within a macro group is the manhour requirement standards from each of the various production shops.

During the overhaul, each of the various types of aircraft requires from twelve to fourteen separate in-process phases. Over all of the different product types a total of seventeen distict in-process phases were identified. In order to allow for adaptation of the scheduling system to other product groups, the decision was made to allow for up to twenty-four separate product phases.

The characteristics described for the scheduling system up to this point are the only ones that have remained unchanged since the beginning of this interactive scheduling project. The number of standard products has changed, but the list of characteristics by which one can distinguish one product type from another has remained constant. Under the category of aircraft overhaul products one can summarize their characteristics as follows.

(a) Each type of aircraft falls into a distinct MACRO group. All types within that group have deterministic and identical:
   (1) In-process phase sequencing,
   (2) In-process phase durations, and
   (3) In-process phase space requirements on the same assembly lines.

(b) Each type of aircraft has its own unique set of manhour requirements from each of the various production shops.

(c) Any particular aircraft may be determined to be a nonstandard product type. At the time of such a determination, that aircraft will be assigned a new set of in-process phase durations and a new set of manhour requirements. The sequence in which the in-process phases are performed will remain unchanged.

Figure 2.1 depicts a typical in-process phase sequence flow. One major aspect of this diagram is the fact that two or more phases may overlap in time. Therefore, this real-world system is much more general than the normally accepted flowshop model.

One facet of the product types associated with this system that is especially noteworthy is the fact that the in-process phase lengths are

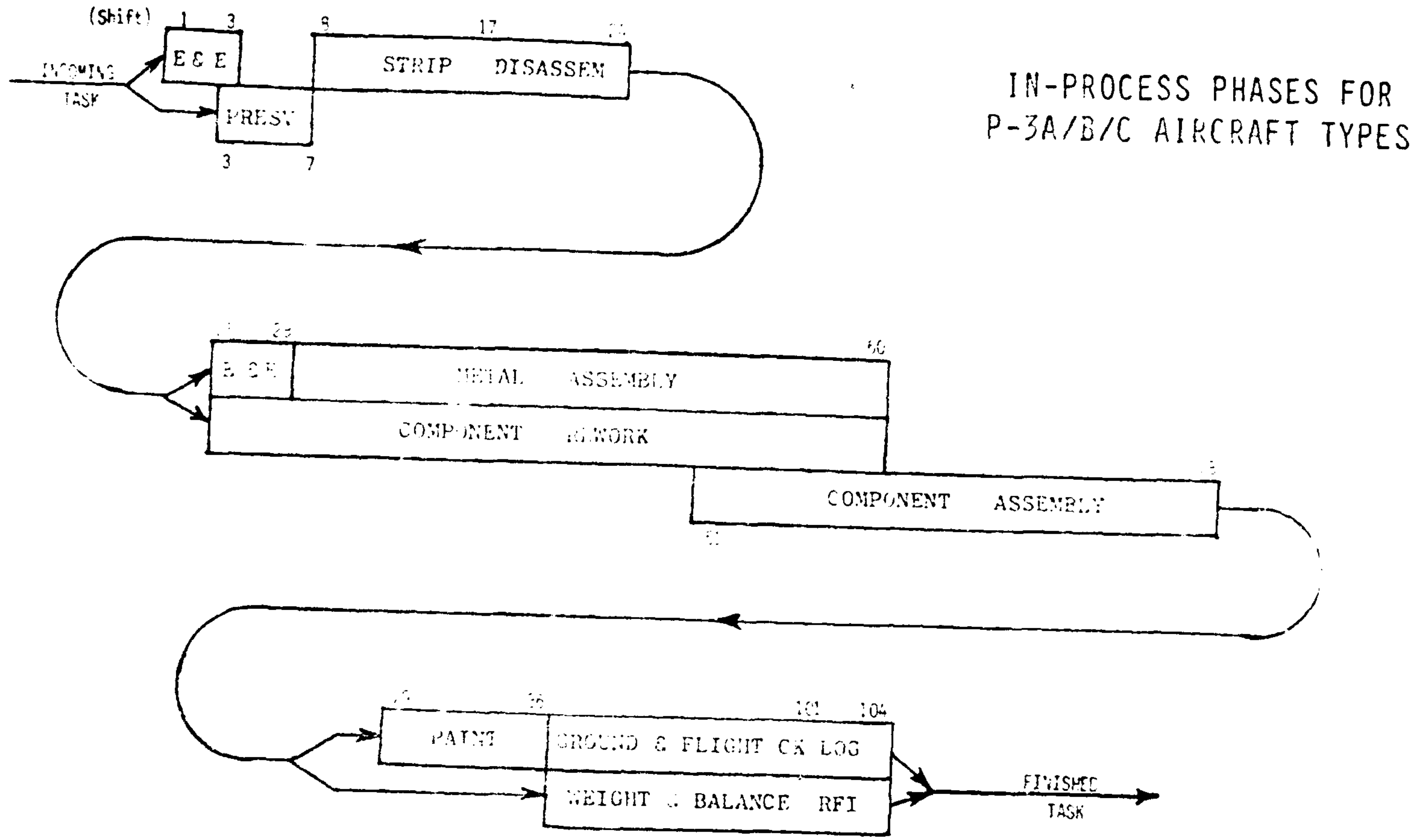

Figure 2.1 Typical In-Process Phase Sequencing and Durations

entirel deterministic. This means that the scheduler is only concerned with starting times for the initial phase. This facet simplifies the problem, but at the same time restricts the number of degrees of freedom available in schedule development.

2.1.2 Nonstandard Products

As indicated above, standard products can be designated as nonstandard at certain points during their overhaul. In addition, some products can be determined to be nonstandard prior to their induction into the system. For example, in some cases an aircraft may have been subjected to minor damage shortly before its scheduled induction for routine overhaul. Such an aircraft could be declared nonstandard and a new set of phase durations and manhour requirements assigned. Another example, even more common, is the instance where a particular aircraft is scheduled to undergo major modifications in order to equip it for an entirely new type of mission; i.e., a patrol aircraft may be changed from an antisubmarine type to one more suited to hurricane surveillance. Again such a type is said to be a nonstandard. The single characteristic common to all nonstandard overhauls is that they are unique to themselves with respect to resource requirements and phase durations.

The scheduler is unable to effect any changes in the induction dates for aircraft that become nonstandard after the start of their overhaul. It is, however, necessary that their impact on resource requirements be taken into account in the development of schedules that affect the period during which such nonstandard aircraft are in the repair/overhaul system.

The scheduler may be able to select the desired starting date for nonstandard types that are so declared before their induction. On the other hand, the starting date for such a unique type is often predetermined by the date it is to be made available for modification, or it is dependent on the date it must be made available for use on the new mission. This leads to the requirement that the interactive scheduling system must include the capabilities to preschedule certain product starting times before inserting any variable starting time products into the schedule being developed, and then to hold those prescheduled starting times fixed during any subsequent heuristic improvements to the schedule.

2.2 Generalization of Product Types

Recalling the second and the sixth of Godin's hypotheses for the cause of failures, it is apparent that any interactive scheduling system designed to be adaptable to a wide variety of product lines must be flexible enough to both allow for rapid changes in the product line for the system to which it has been applied, and to eliminate the need for custom design when it is adapted to a different production system. At the same time it must be sophisticated enough to allow an easy method for the user, with a minimal amount of training on the scheduling system, to create new standard and nonstandard product types within the data base. This latter feature is also applicable to the user training-cost aspect of the sixth hypothesis. The management information system described in subsequent chapters was designed with these characteristics in mind, especially with respect to freedom in the definition of product types and their resource requirements. The method chosen to accomplish this will be discussed in detail at a later

point. In general, however, it was achieved through definition of the data for standard product types in a disk-stored, card-image file that is formatted in such a way that it is easily read and changed by a user from a computer terminal, who need not understand the program that reads that file and uses it to create a structured data base.

Nonstandard products are added to the data base through an interactive program that prompts the user by asking all of the questions necessary to allow creation within the structured files of the information required to schedule such products and to determine their impact on resources.

Deletion of standard types that are no longer applicable is done by removing them from the card-image file. Deletion of nonstandard types is done by an interactive program.

The methods chosen for definition of product types will allow rapid and easy adaption of the scheduling system to other product lines with the only requirement being the creation of a card-image file to define the standard products. Since the format of that file is fixed, only the variable data associated with products must be inserted.

2.3 Description of Resources

2.3.1 Production Shops

The manhour requirements for this facility are defined in manhours per type of aircraft from each of the production shops. Therefore a production shop may be considered as a resource.

At the production facility for which this interactive system has been developed, each of the more than one hundred production shops

may be associated with at most two of the different in-process phases. The association of each shop with particular phases remains constant across all product types. In addition, when there are two phases, then the two phases may be equivalenced to each other as being the same phase. This allows the computer programs in the interactive system to relate each shop with a particular in-process phase and thereby to allocate the manhours from that shop for each type of product across those production shifts during which that product type is in the associated in-process phase.

2.3.1.1 Generalization of Production Shops

The fact that the production shop resources are, in this case, related to shops is an implication that exists only in the card-image file mentioned above. Requirements may be considered as applicable to any resource that is utilized for any product types that need be associated with one or more distinct time periods during the processing of that product.

Further generalization of the computer system to other production facilities is easily attained. For example, if a production shop, or its surrogate in a different plant, can not be associated with a unique in-process phase across all product types, then one has only to create either fictious in-process phases, or fictious production shops or both. These fictious elements are then included in the data base description of the flow sequences for product types, and the resource requirements are then allocated across the real and fictious elements according to their actual distribution between them.

2.3.2 Trade Skills as a Resource

For this aircraft rework facility management considered that each trade skill represented a resource and that some of these trades were critical. The system developed includes a capability to evaluate the impact per unit of time of a given schedule upon resource requirements in two fashions, namely upon each of the approximately fifty different trades represented on the payroll, and upon the more than one hundred production shops in the organization.

The resources represented by trade skills could not be related directly to a single in-process phases, or to a single surrogate. In addition, data were not available to relate the number of manhours required from any trade skill to process each of the different product types. In other words, management was asking for the computer system being developed to measure an attribute of the production system which had not been measured in the past.

The solution was to develop data that allocated the manhour requirements from production shops to the trade skills assigned to those shops in a ratio representing the actual requirements within each shop. The allocation within each of the shops is assumed constant across all products, not because that is required by the scheduling system but because this is the only data allocation available to management

This allocation of the hours from each production shop to its particular set of trade skills is also accomplished by data described within the card-image file. This allows it to be easily modified in the future as improved historical data on the allocations become available.

2.3.3 Generalization of Resources

Inclusion of the capability to handle trade skills as a resource greatly increased the flexibility of the scheduling system to handle the requirements of other facilities when adapted thereto. The result is that, by simple changes to the card-image file, one can represent extremely complex relationships between resource requirements which might otherwise have to be assumed away. It should be noted that this feature has very positive implications with respect to Godin's first hypothesis on assumptions causing failure.

Each of the resources constraining the development of schedules that have been described to this point is related solely to manhours. That relationship, however, is strictly an implication of the user and has no bearing on the data structure developed and used by the interactive scheduling system. In reality, the system could be used to represent any resource that can be related to usage per unit of time during the processing of a product. For example, the resources considered by the system might, at the same time, represent such diverse inputs as inventory items, space for work, or delay between work functions, electrical power, tools, etc.

2.4 Constraints

The consideration of constraints within this development is an extension of the direction that was started by Per-Olof Carlson [3]. His approach was to model the scheduling problem as a Zero-One Integer Program wherein the objective was to minimize the maximum violation of the constraints. The model thus developed was then solved by implicit enumeration techniques applied to the decision tree that

could be associated with the Zero-One Program. The effective result of this approach is to relax all the constraints while at the same time associating a cost with the excessive utilization of the resources represented.

The main feature that precludes the application of Carlson's method to the problem at hand is the vastly larger size of this scheduling problem compared to that on which Carlson was working. Both problems can be solved by implicit enumeration; however, the computer execution time necessary to optimally solve the flowshop scheduling problem is prohibitive, as should be expected for any large, np-hard problem.

The concept of constraint relaxation was retained in this application, as was the objective of developing a schedule that minimizes some measure of the deviation from the mean requirements for critical resources considered singly or in combinations. In action, the system allows the user to assign criticality to certain resources, and then to have the computer heuristically develop a schedule in an attempt to level the requirements per unit of time of those resources.

Additional constraints to the system do exist, and they can be handled in a separate manner. For example, one of the product types requires eight shifts (four work days) to paint and there is room to paint only one at a time. In effect this is a bottleneck problem that can be handled by setting a minimum time between starting any two of these products. The deterministic aspect of in-process durations allows this solution procedure to be applied. The end result of constraints of this type is a reduction in the number of feasible schedules that must be considered during heuristic development of an initial proposed

schedule, improvement of a proposed schedule or making changes to an active schedule.

The data necessary to solve the bottleneck aspects of this problem are also contained in the card-image file and are therefore easily changed, either to adapt to changes in the environment of a current application or in the employment of the computer programs for an entirely new facility.

One noteworthy feature of this application is that it takes advantage of the possibility of combining two or more such constraints into one and thereby reduce program execution times.

2.5 Miscellaneous Aspects of the Product System

2.5.1 Variable Time Units

The aircraft facility involved in this study utilizes five different time units for various functions involved in scheduling. Two of these units, shifts and days, are associated with the allocation of resource requirements, and the other three are associated with both the development of schedules and the publication of future workloads to each of the production shops involved. The latter three units are the work-month, work-quarter, and the work-year. The length of these three vary from every time period they measure to the next such time period.

The relationship between shifts and days (number of shifts per day) is included in the card-image file. This allows the system of programs to be exported to other facilities that work a different number of shifts per day. For more complete generalization it also allows the

assignment of other time-unit relationships. For example, the case where in-process phase lengths are to be measured in hours while resource availability or requirements are given in days. The only limitation on this relationship in the current computer programs is a function of program data size to fit in core memory. At the current time the number of days has been limited to sixty-six, the upper limit on the number of work-days per work-quarter.

The relationships between work-month, work-quarter, and work-year are measured in days, and are input into the programs by the user in response to appropriate interactive queries. By his response to these queries, the user may select the desired lengths for scheduling horizons, data extraction and compilation, and displays of the resource requirements for selected resources.

2.5.2 Future Product Quantity Requirements

As is the case with a majority of production facilities, the scheduler has access to forecasts of the number of each type of product that will require processing during some future time frame. In this system, the data are in the form of "number of each type per quarter" over a two year future horizon. Although these data are highly subject to change, they are used to develop forecasts for future resource requirements. In this particular application the data are now being utilized to provide the personnel section of the plant with a forecast of future hiring and training requirements by trade skill. Historical data on attrition rates for each of the trade skills were available prior to development of the scheduling system data base, but were unusable for the prediction of hiring and training requirements because there had

been no method of predicting the number of workers needed within each trade skill in order to meet a future product demand. Data spin-offs of this type are particularly useful in convincing potential purchasers of the attractiveness of the scheduling system, one aspect of Godin's sixth hypothesis.

CHAPTER 3

DEVELOPMENT OF COMPUTER PROGRAMS AND FILES SYSTEM

3.1 Background and Chronology

The developer of this system recognized at the onset that any one of many aspects of the system and its development could lead to failure of the entire system. Godin's article [8], published some six months later, lent structure to this observation. One example is that, in the very beginning, it was readily apparent that the potential users were unfamiliar with the use of computer-based systems for purposes other than budgeting, and that they had no way to evaluate the impact of the schedules they created.

The lack of familiarity of the schedulers with computer-based systems meant that three factors would greatly impact on the development of the system: (1) the schedulers could not readily envision either the possible applications that could be developed, or the usefulness of such applications should they be developed, (2) they could not explicitly describe the kinds of applications that they desired in terms which were sufficiently definitive to provide the developer with a sound basis for design of the final product, and (3) the developer could not envision the applications needed, nor describe many of the applications he envisioned, in terms that were sufficiently meaningful to the future users to allow them to evaluate and comment on applications.

The problem facing management in this instance was the rapid swing in the daily manhour requirements for the critical trade skills. These swings occurred as the result of the product induction schedules

currently being created by hand. A major facet of the problem was the fact that there was no means by which one could predict the day-to-day requirements that would accrue as the result of a given schedule. In other words, the implications of a bad schedule could not be readily evaluated, nor could the effects of changes to an already created schedule be analyzed.

Recognition of the factors of unfamiliarity on the one hand, and inability to evaluate on the other, led to two major decisions prior to the beginning of computer programming efforts. The first of these was to conduct the entire development of the system in a two-way feedback environment of develop-try-modify. The second was to begin development with the creation of a management information system (MIS) for use in the evaluation of manhour requirements for a given schedule. The MIS was also a necessary foundation for the later portion of the computer system, which was to be used to develop schedules that would reduce the swings in manhour requirements.

The basic concepts of the two-way feedback environment are depicted in Figure 3.1. The concept lying at the heart of the system is one of passing ideas and recommendations in two directions, and to develop the system creatively as a result of the increasing comprehension on both sides; an increase growing out of an almost constant interchange of ideas between user and developer.

In the development of any computer-based system, the first step is to ascertain what features and capabilities the user desires in the system through a series of conferences in which ideas are exchanged between the user and the developer. This stage is depicted in Figure 3.1 by the square box in the JOINT EFFORTS column which is labeled "Initial Ideas for Segment N," with N equal to 1. This stage is common

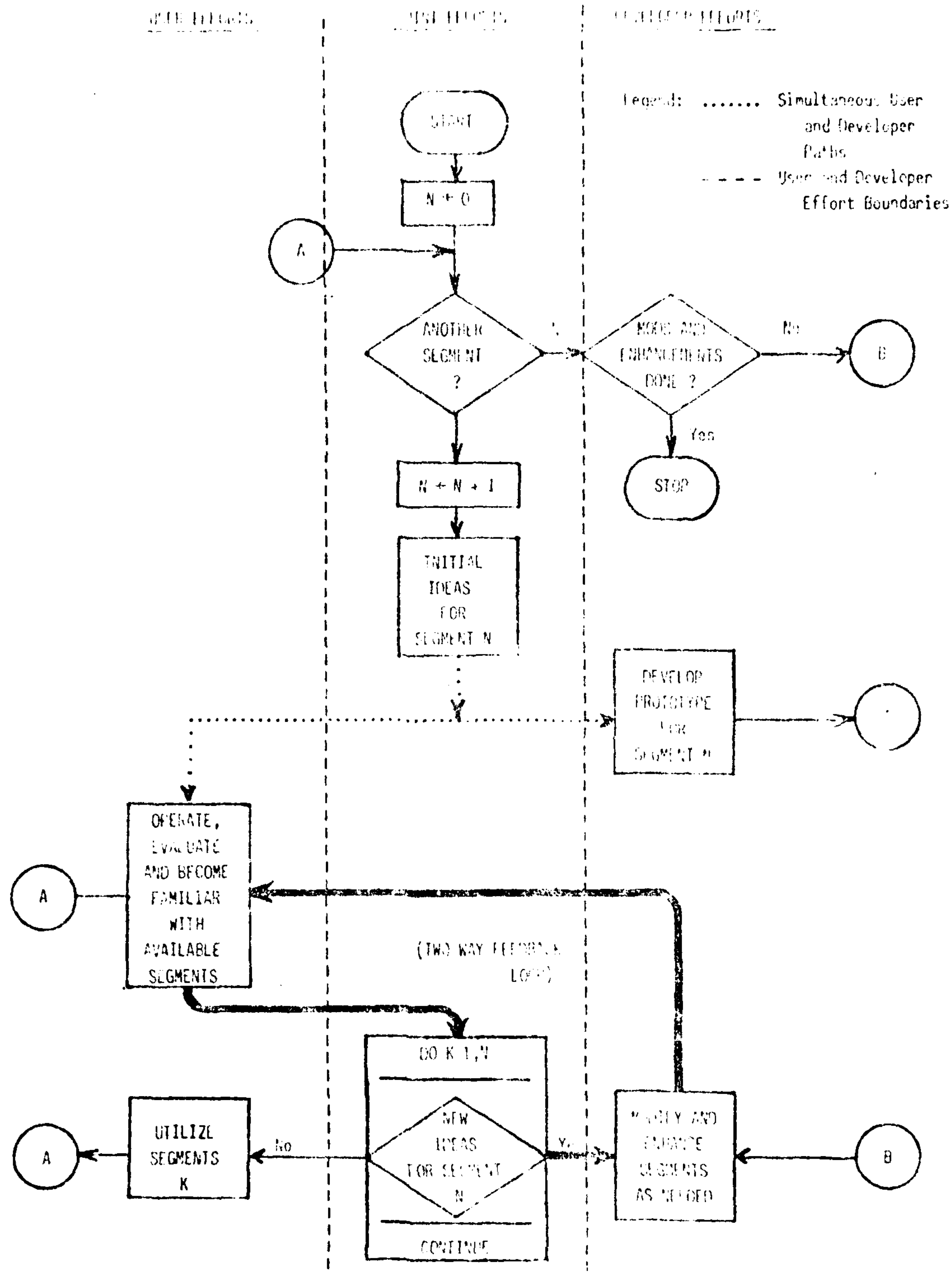

Figure 3.1 Schematic of System Development in a TWO-WAY FEEDBACK Environment

to all methods of computer system development, however, the normal practice is for the developer and the user to create a set of system specifications for the entire system at the conclusion of such conferences. Then the normal practice is for the developer to create the system in its entirety based upon those specifications; creation in isolation so to speak.

In this instance that was not done. Instead, the developer left these conferences with some, often vague, idea of what the user really wanted, recognizing that the user had no grasp of what the system would be capable of accomplishing in the end. This lack of comprehension was due, in great measure, to the user's lack of familiarity with computers. At the same time, the developer also lacked familiarity with the problems, needs, and requirements of the user.

In a two-way feedback environment, the developer leaves the initial ideas conference and proceeds to the upper square block in the DEVELOPER EFFORTS column of Figure 3.1. He "Develops a Prototype for Segment N." This prototype is not intended to be the final product for that segment, therefore it can be very simplistic in its design and features. The role of the prototype is to stimulate the interchange of ideas in order to enhance future versions of the system.

The user then comes back into the development, performing the "Operate, Evaluate, and Become Familiar with Available Segments" task depicted in the upper rectangular box in the USER EFFORTS column of Figure 3.1. This represents the entry point into the 'two-way Feedback Loop' for the intial prototype for each segment that is developed.

A short period of time after the entrance of a segment into this feedback loop, the user and developer again confer on the entire system, this time with a view toward the development of specific changes to all of the then available segment prototypes. This conference is represented by the DO loop depicted within the rectangular box at the bottom of the JOINT EFFORTS column of Figure 3.1. It is important to note that ALL of the then available segments are discussed at this point The development of a feature within one segment commonly points to enhancements that may need to be incorporated within other segments, including segments that are considered to be finished and those which are in the initial prototype development stage.

Following these modification conferences, the developer then proceeds to modify and enhance all of the segments for which new ideas have been developed. This is depicted as the third box in the 'two-way Feedback Loop,' located at the bottom of the DEVELOPER EFFORTS column of Figure 3.1

Those segments for which no new ideas are developed then move to the bottom box in the USER EFFORTS column. Note that the box is not labeled "Finished Segments K." Instead, it is labeled "Utilize Segments K," implying that the segments for which no new ideas are currently being incorporated may well be modified and returned to the 'Feedback Loop' at some future point in time.

Each major segment of the final system described in this dissertation invariably went through a number of iterations around the 'Feedback Loop' before becoming semi-fixed in its features and capabilities.

A necessary feature of the feedback loop is rapidity. It is worth noting that a concerted effort was made to complete modifications and enhancements in a very short time, normally less than two weeks and often in two or three days, in order to have the modified system into the hands of the user as quickly as possible. This was accomplished in order to maintain a high interest and confidence in the development efforts.

It is obvious that the development of a major, computer-based system in such a rapid, two-way feedback environment is time consuming. However, it has a far greater chance of overcoming, if not avoiding altogether, the causes of failure for completed systems, particularly those failures related to excessive assumptions, lack of flexibility, and the unfamiliarity of the user with computer based systems.

Not as obvious to the reader, but easy to comprehend, is the interest in, and the concern for, the final success of the interactive system exhibited by the user during the creation of the system in such a feedback environment; even to the extent that it may well ensure the final acceptance and the ultimate success of the system before its completion. User involvement in the actual development is the key to this feature.

Another facet of user involvement during the evolution of the system is the reduced amount of user training that is required upon the completion and final installation of the system. This comes about both because of his operation and evaluation of the prototype models, and because of the fact that many of the features incorporated are those for which he himself has developed ideas and requirements.

Another aspect in this particular instance is important to the development methods being used. The actual program writing and debugging was done on the user's computer system. This caused some conflicts between user and developer because of degradation problems with the data base during debugging operations. The solution was simple. Two separate computer operating areas were developed in the interactive control system. The one used by the developer contained all segments in their current state of development. The other contained those segments of the system being utilized, operated, and evaluated by the user. Destruction of the data base in the developer's area left the user's intact and facilitated recreation of the developer's data base.

Table 3.1 contains a non-exhaustive chronology of the interactive, computer-based system described herein. A brief review of that chronology will provide the reader with some insight into the dynamics of developing a computer-based system in this environment. In particular, one should note the large number of enhancements that were not envisioned by either the user or the developer at the beginning but were conceived, developed, and added at a later time. The reader may find it convenient to refer back to Table 3.1 during the discussions which follow in this chapter.

3.2 Management Information System

This section will contain a brief description of the two management information systems that have been developed during the evolution of this system. The first of these MIS was a small-scale prototype based upon the original user assumptions that only one trade skill was

Table 3.1

CHRONOLOGY OF SYSTEM DEVELOPMENT

DATE	MAJOR EVENTS	MODIFICATIONS AND ENHANCEMENTS
May, 78	Initial introduction to problem.	
Jun, 78	Initial conferences to define system and obtain data on products, production phases, production shops, and trade skills.	
Jul, 78	Prototype, trade skill manhour prediction program (PSKILL) using test data.	
Aug, 78	Initial MIS using real data.	Hard copy of production histograms. Printed tables of manhour requirement data for selected skills. Printed composite table of daily requirements for every skill.
Feb, 79		Creation and use of non-standard product data in predictions.
May, 79	Need to expand to multiple trade skills per shop.	Increased trades from 19 to 49. Increased production shops from 114 to 125. Redesign of raw data files to ease their modification. Expanded size of all data files.
Jun, 79	Ran revised MIS for expanded trade skills and production shops.	

Note: Names of computer programs are shown in parentheses; e.g. (PSKILL). Chronology is not exhaustive.

Table 3.1 (Continued)

July, 79	Improved methods for creation of non-standard product data (NONSTAND and DELETE). Capability to predict daily trade skill requirements for any selected production division, branch, or segment (SEGMENT). Prototype program to predict daily manhour requirements for each production shop (PSHOPS).	Print out of GANTT Charts Added non-production shops to shops records, listings and predictions. Tabular print out of daily requirements for selected shops. Printed composite table of daily requirements for every shop.
Aug, 79	Prototype program to predict average daily trade skill requirements within production shops (PLOADS). Started schedule development segment of MIS. Doubled file sizes to allow standards for both previous and current quarters.	Expanded schedule from one to two years.
Sep, 79	Proposed schedules developed (SCHEDULE, and UNIFORM). File and record management program developed (RECORD).	Selectability of variable horizon lengths (PSKILL and PSHOPS). Division and branch subtotals (PLOADS). Separation into "developmental" and "operational" systems on computer.
Oct, 79	Heuristic development of proposed schedules (HURESTIC).	Expanded (PLOADS) records to twelve quarters. Prediction of employee availability and attrition by trade skill (PLOADS). Prediction of future trade skill employment and training requirements (PLOADS).

Table 3.1 (Continued)

Nov, 79		Choice of real (current) or proposed schedules (PSKILL and PSHOPS).
Jan, 80		Expanded file and record management capabilities (CLEANOUT, SKED11, and COMPONENT) Added monthly records to (PLOADS). Creation of monthly and quarterly man-hour requirement records for production shops (PSHOPS). Access of (PSHOPS) monthly and quarterly records for shops by (PLOADS). Worker availability predictions for all trade skills (ATTRITION). Extended schedule to two years and eighty days.
Feb, 80	Creation of improved/final schedules (ONEWAY) Statistical comparison of hand made, heuristic, and improved schedules (COMPARE).	Printout of selected schedules in day order by month (PSKILL). Minimum, maximum, mean, and standard deviation statistics for daily requirements for shops and trade skills (PSKILL and PSHOPS).
Mar. 80	Overtime hours comparison of schedules from various sources for all, individual, and critical trade skills (PSKILL).	Run-in and run-out hours for selected period (PSHOPS). Hour requirements prediction for selected product types (PSKILL).

Note: Names of computer programs are shown in parentheses; e.g. (PSKILL). Chronology is not exhaustive.

assigned to each of the production shops, and that there were only nineteen trade skills in all within the entire production system; assumptions that had been the basis for production scheduling for the past few years. The second MIS resulted when the user indicated a desire to change to the more realistic conditions where more than one type of trade skill is assigned to a given production shop (actual analysis indicated a maximum of eight different skills in any of the shops) and the fact that forty-nine different trade skills could be identified within the facility, rather than the nineteen used in hand-scheduling operations.

3.2.1 Initial Management Information System

The management information system whose structure is shown in Figure 3.2 was developed using the initial data and the parameters that were provided at the beginning of development of the system. Table 3.2 contains a listing of the original parameters.

3.2.1.1 Manhour Prediction Program

The program named PSKILL shown at the bottom of Figure 3.2 was the initial user program for predicting the daily manhour requirements for each of the nineteen different trade skills assumed to be involved in production. The predictions calculated by this program were based upon the schedule of aircraft inductions contained in the file named SCHEDULE Data shown on the lower left side of Figure 3.2.

The PSKILL program contained the following features available for selection by the user:

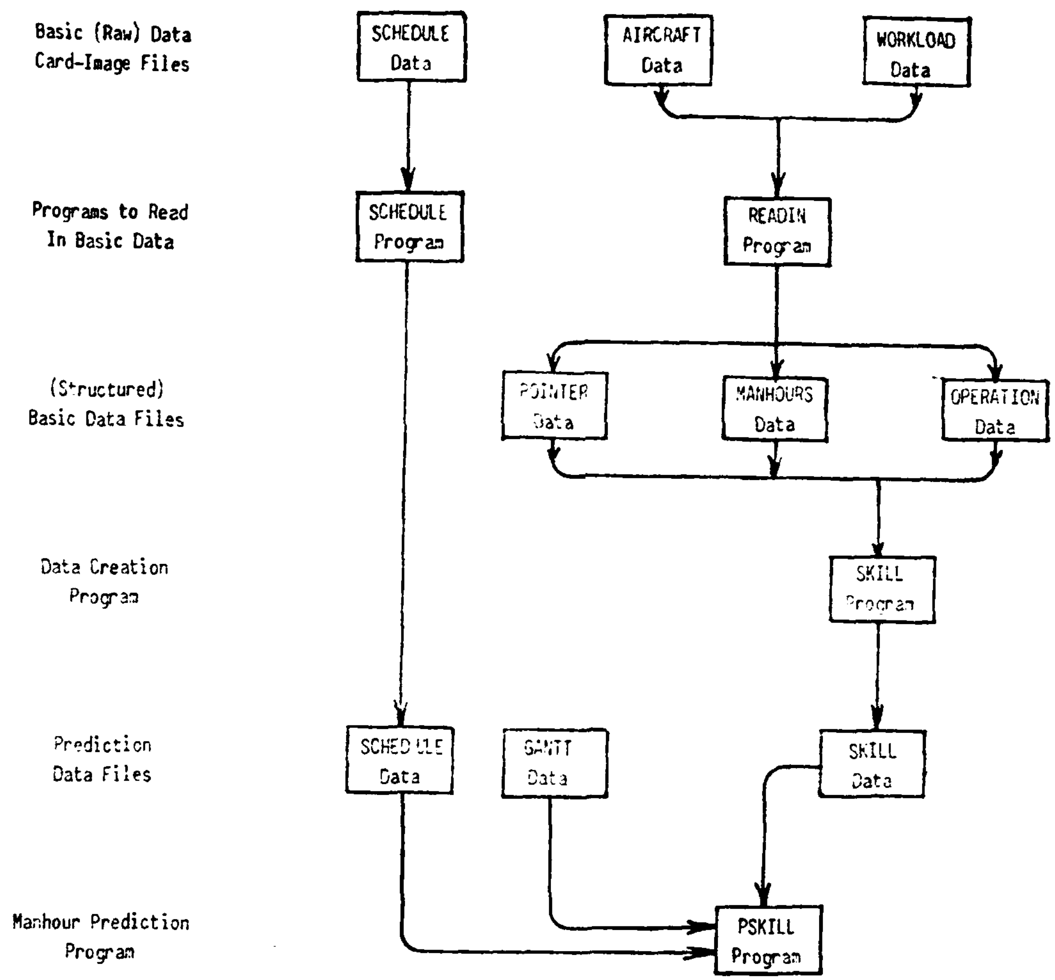

Figure 3.2 Structure of the Initial MANAGEMENT INFORMATION SYSTEM

Table 3.2

(INITIAL)
PRODUCTION SYSTEM PARAMETERS

Product Descriptions	Quantity
Standard Product Types	18
Nonstandard Products	None
Production Phases	16
Resources Considered	
Production Shops	114
Trade Skills Involved	19
Trade Skills per Shop	1
Standards (Manhours per shop for each product type)	
Manhours (Change quarterly)	Current Quarter
Schedule-Lengths	
Scheduling Horizon (For creating schedules)	65 Days
Length in System Data Base	1 Year

(a) CRT Display of a histogram representing the daily manhour requirements for a sixty-five day period. The beginning date of the period and the trade skill could be selected interactively by the user.

(b) The schedule of inductions upon which the daily predictions were based could be modified interactively.

(c) A hard copy of the histograms and the current schedule being considered could be created for print out upon termination of the program.

(d) A GANTT Chart could be created for print out based upon the current schedule being considered. This feature was added during the final days that this version of the MIS was in use.

3.2.2.1 Modification of Basic Data

During the early evaluations of the initial system it became apparent that two additional features had to be added; a capability to incorporate nonstandard products for temporary inclusion in the data base, and the ability to modify the basic data to account for permanent changes in the production system. The latter of these includes the quarterly modification of the workload standards for the standard products.

The modification of the data base to account for permanent changes was initially done at the Basic Data (Card-Image) file level by replacing the actual cards with new cards containing the modified data. This procedure was soon abandoned and replaced by editing of the card-image files stored on the disk. This editing was done using the interactive edit mode available in the computer system executive software. Three different interactive programs were written in an attempt to facilitate the making of such permanent modifications. All three failed, however, before actually being incorporated in the MIS. Each of these failures resulted from the program lacking sufficient

sophistication to allow for all, feasible changes that could possibly occur in the future. The result of each failure was that any changes required had to be made in the interactive file edit mode. These efforts were made more difficult by virtue of the fact that the original card-image records had been formatted in a fashion that was amenable to being read by a machine, but not to being read by a human. The subsequent change to the format of these files, described later, represents a major step in overcoming Godin's hypothesis on failure due to inflexibility.

3.2 Revised Production System Parameters

At approximately the same time as the publication of Godin's article [8], a new set of data was provided by the Naval Aircraft Rework Facility. The new data were far more extensive than the original in the allocation of production shop manhours to trade skills. Unknown to the developer at the time, the original data represented trade skill allocations that had been greatly simplified in order to make the hand calculations more tractable. In fact, since no calculation of trade skill, daily manhours had been done, the assumption of only one trade skill in any given production shop had been satisfactory. However, the new data showed that the number of different trade skills assigned to a single shop varied from one to eight depending on the shop, and that number could become larger in the future. In addition, the number of trade skills was not nineteen, as originally stated, but was more than forty, a number which could also grow during the future.

Immediately prior to these data coming to light, the organization of the production shops had changed and their number had grown from

the original one hundred fourteen to one hundred sixteen. In addition, the user decided that the non-production shops should also be included due to the fact that they contributed, what are called, non-direct labor manhours. The net result was a growth to a total of one hundred twenty five shops.

These changes were indicative of the flexibility requirements for the management information system. In the light of these changes to the production system parameters the decision was made to scrap the, then running, management information system and to start over with a new design for the Basic (Raw) Data Files. The goal for the new design was to increase the flexibility of the system to incorporate the numerous changes it would undergo in the fuutre, and to make the incorporation of those changes by the user a much easier matter. The basic system structure depicted in Figure 3.2 was retained as a starting point. The (Structured) Basic Data Files were extended to include the additional records dictated by the increased number of trade skills and production shops. Table 3.3 is a compilation of the parameters for the production system.

3.2.4 Revised Management Information System

Figure 3.3 depicts the structure of the complete, revised management information system. The growth in the number of elements between Figures 3.2 and 3.3 has resulted primarily from the incorporation of additional features requested by the user. The movement from the simple beginnings envisioned by both the user and the developer to the more complex MIS represents, in large magnitude, the increased familiarity of operation managers with the use of

Table 3.3

(REVISED)
PRODUCTION SYSTEM PARAMETERS

Product-Descriptions	Initial	Revised	MIS Limit
Standard Product Types	18	17	Note 1
Nonstandard Products	None	Variable	Note 1
Production Phases	16	17	24
Resources Considered			
Production Shops	114	125	128
Trade Skills Involved	19	49	60
Trade Skills per Shop	1	1 to 7	10
Standards (Manhours per shop for each product type)			
Manhours (Change quarterly)	Current Quarter	Past and Current Quarters	Past and Current Quarters
Schedule Lengths			
Scheduling Horizon	65 Days	Up to 66 Days	Up to 66 Days
Time in System Base	1 Year	2 Years and 80 Days	2 years and 80 Days

Note 1. Up to 32 total standard and nonstandard products.

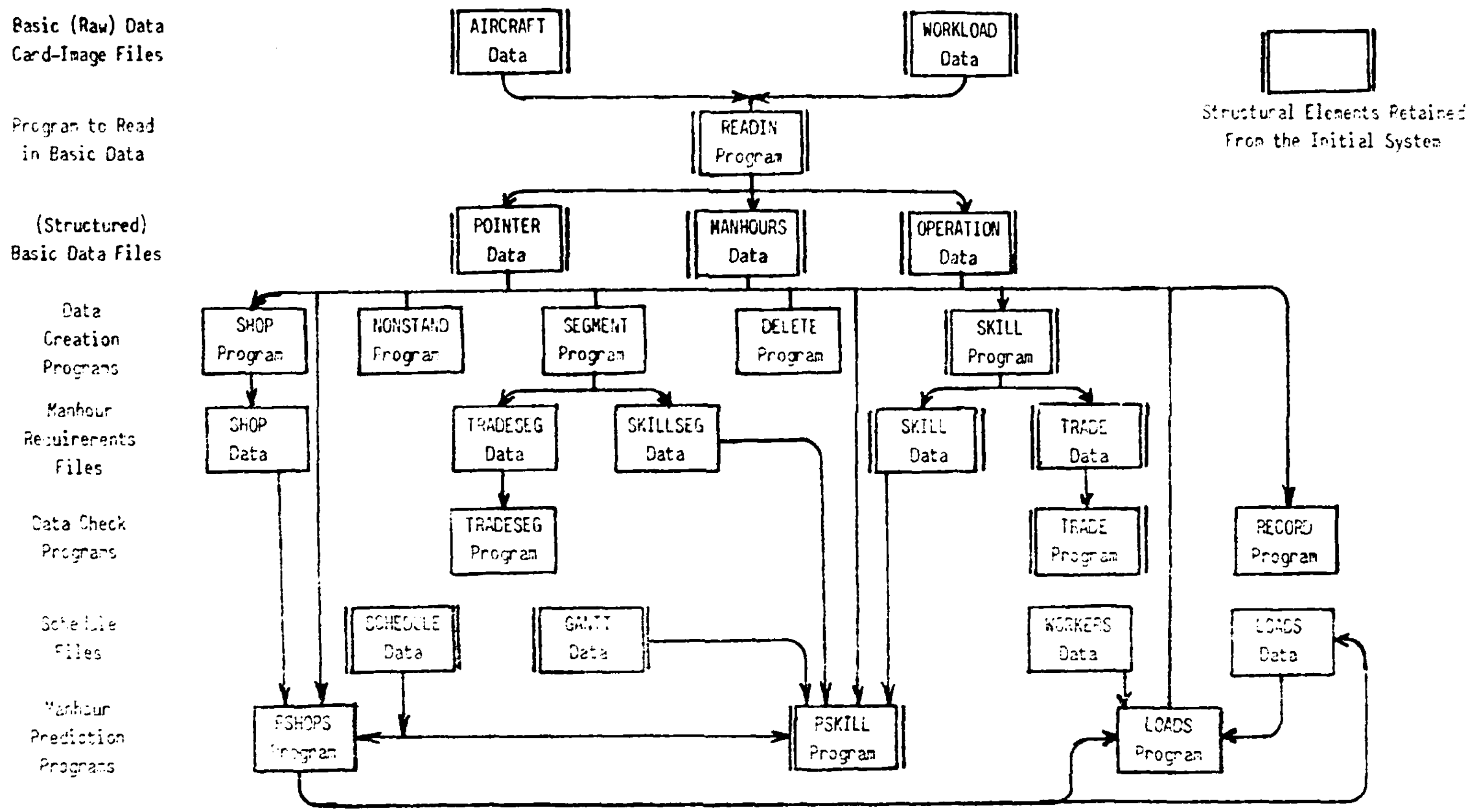

Figure 3.3 Structure of the Revised MANAGEMENT INFORMATION SYSTEM

computer-based information systems, to wit, an overcoming of Godin's fourth hypothesis for failure.

3.2.4.1 Basic Data Segment

The Basic Data segment of the revised management information system is depicted in Figure 3.4. The structure for this segment is identical to the corresponding segment for the earlier version of the MIS except that the internal structure of the two Basic (Raw) Data files, AIRCRAFT and WORKLOAD, is considerably changed.

In both versions these two files are read by the computer, and changes of these two are accomplished by editing the card images of the files which are stored on the external memory disk system of the computer. In the first version the format of the files was designed entirely with the computer's accessing of them in mind. The revised version consists of files which were designed to be read by the user during the incorporation of changes in the data. As a result, the program named READIN had to be greatly modified to account for the large quantity of explanatory data in the files; data which are ignored by the computer, but are included to facilitate comprehension of the files by the person making changes. In the vernacular of computer professionals, one could say the original files contained "packed data," whereas the current version contains "documented, unpacked data."

As in the earlier MIS version, the structured files of basic data originially contained only the data applicable to the current quarter. A joint decision of the user and the developer had then considered this "lack of history" acceptable and all predictions were made based on the workload standards for the current quarter, whereas in reality the scheduled aircraft could possibly come under the standards for different

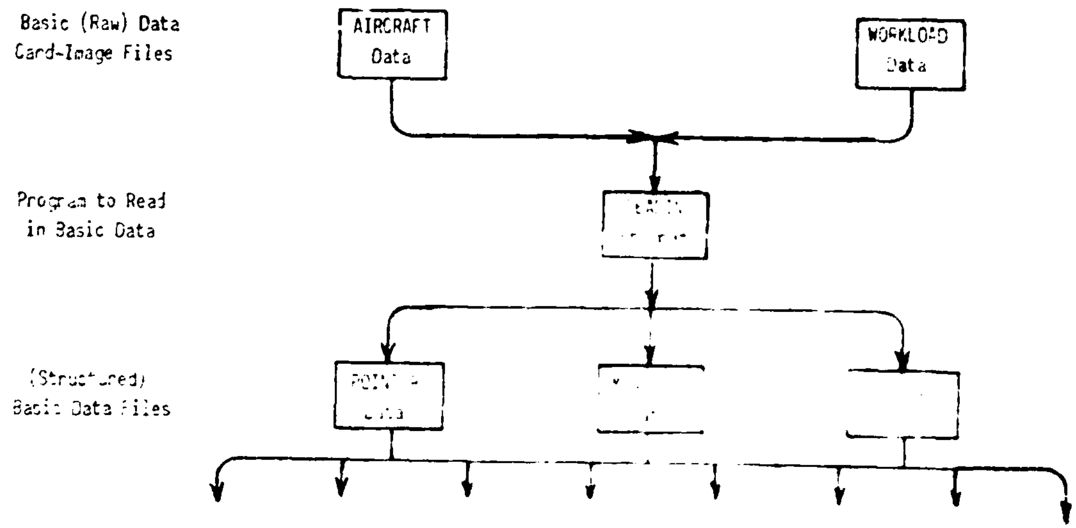

Figure 3.4 Structure of the BASIC DATA SEGMENT of the MANAGEMENT INFORMATION SYSTEM

quarters. To correctly calculate these values one would have to use the standards for each product that were applicable at the time its overhaul first began.

Subsequent to the application depicted by the PSHOPS Program element (lower left corner of Figure 3.3), it was jointly decided that the data files labeled MANHOURS, and OPERATION, SHOP, TRADESEG, and SKILL must be expanded to include the standards for two periods, current and previous quarters. The errors between the computed values using only one quarter's standards and the real totals demonstrated error rates of from 2 to 5 percent of the total manhours required for a given quarter's production. Calculation of the same values by the computer system using the correct quarter's standards for each product reduced the difference between hand and MIS calculated totals to less than one-half of one percent.

All of the data files depicted in Figure 3.3 are order dependent. In other words, the sequence of the records within the files is dependent on the particular elements which those records represent. For example, suppose a new production shop is incorporated into the data for the current quarter. Then in spite of the fact that the new shop did not exist last quarter, a record containing all zeroes must be created and incorporated into the data for last quarter. From this simple example it is readily apparent that the program named READIN had to be extensively modified to allow it to compare the new quarter's data being read in against the previous quarter's data, and, when a significant change occurs, make corrections to the previous data to maintain integrity of the order for the records. Such corrections must be made not only to the structured, basic data files, but also to the

Manhour Requirements Files depicted in the fifth row of Figure 3.3, and to the WORKERS and LOADS Data Files in the seventh row.

3.2.4.2 Manhour Prediction Programs Segment

The bottom line of elements in Figures 3.3 and 3.5 consists of user programs dedicated to the prediction of daily manhour requirements from a variety of viewpoints. In addition, these programs also are capable of providing hard copy outputs of other aspects of manhour requirements.

3.2.4.2.1 PSKILL Program

The PSKILL Program is the first of the three manhour prediction programs, both from the point of sequence in being developed and in importance to the system. However, it may well turn out that the other two programs see more actual use in practice; primarily because they produce enhanced versions of predictions that had been previously calculated by hand.

To begin with, the PSKILL program is mainly designed to provide both CRT display and hard-copy print out of the daily manhour requirements for any trade skill selected by the user, or the summation of all trade skills combined, over a time frame whose beginning and ending dates are also selected by the user.

The following is a list of options available to the user during execution of the PSKILL Program:

(a) At the beginning of execution:
    (1) Range of Production Shops:

        a. The entire range of data produced by SKILL Program, or

        b. The selected segment of shops data produced by the SEGMENT Program.

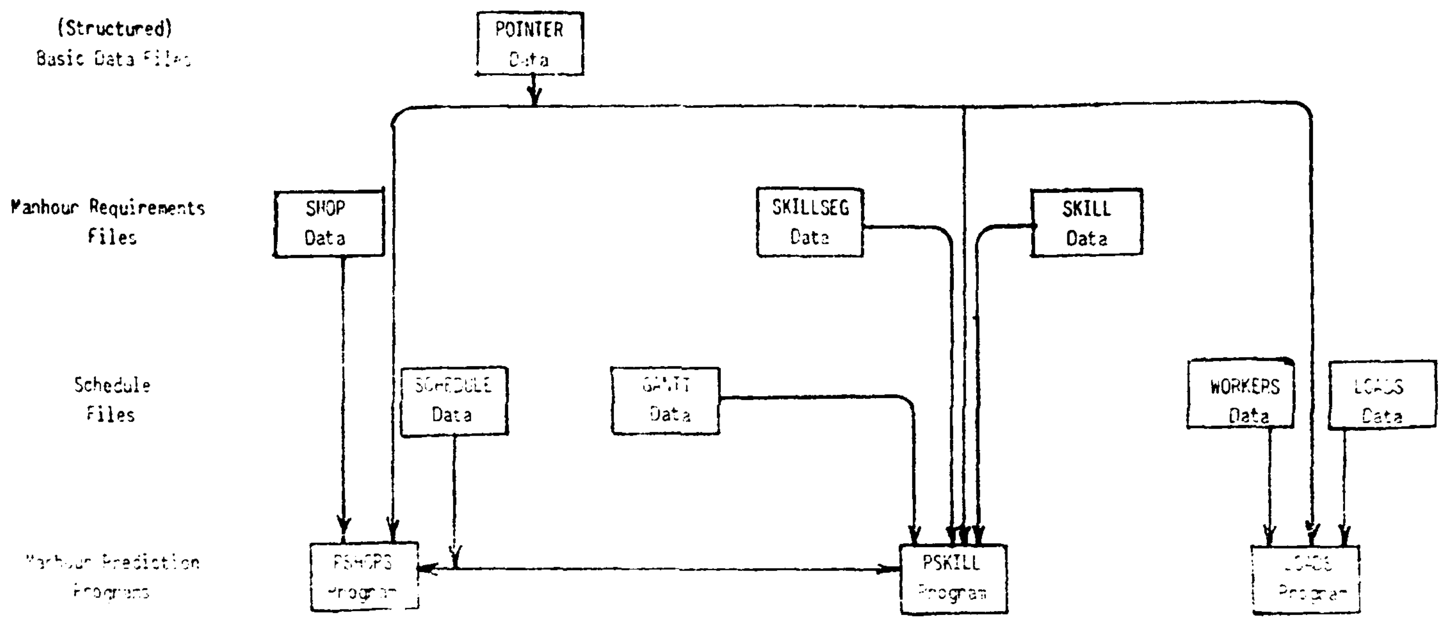

Figure 3.5 MANHOUR PREDICTION Programs Segment of the MANAGEMENT INFORMATION SYSTEM

(2) Initial Schedule:

a. The actual schedule stored in the SCHEDULE Data file, or

b. An experimental schedule produced by the schedule development programs to be discussed later, or by other means.

(b) At any point during the execution; i.e. may be changed during execution:

(1) New beginning and ending dates,

(2) Switch to other schedule type, and

(3) Smoothing of data using three-day running average.

(c) Alterations to the induction schedule:

(1) Additional products may be added, and

(2) Scheduled products may be dropped.

(d) Gantt Charts:

(1) User may select to have Gantt charts printed out for any of the macro product groups, or for all products in the current version of the induction schedule.

(2) The first day represented in the charts output is the first day of the time frame selected in (b) (1) above. The time frame for the Gantt Charts is one hundred thirty two work days.

(e) Schedule:

(1) CRT display of current schedule for any one product type over the selected time frame, or for all product types over the same period.

(2) Hard-copy printout of the schedule(s) displayed on the CRT.

(3) Hard-copy of the current version of the schedule printed in day order by months, a format used by the schedulers during the past.

(f) Daily Manhour Requirements

(1) CRT Display of HISTOGRAM. (See figure 3.6.)

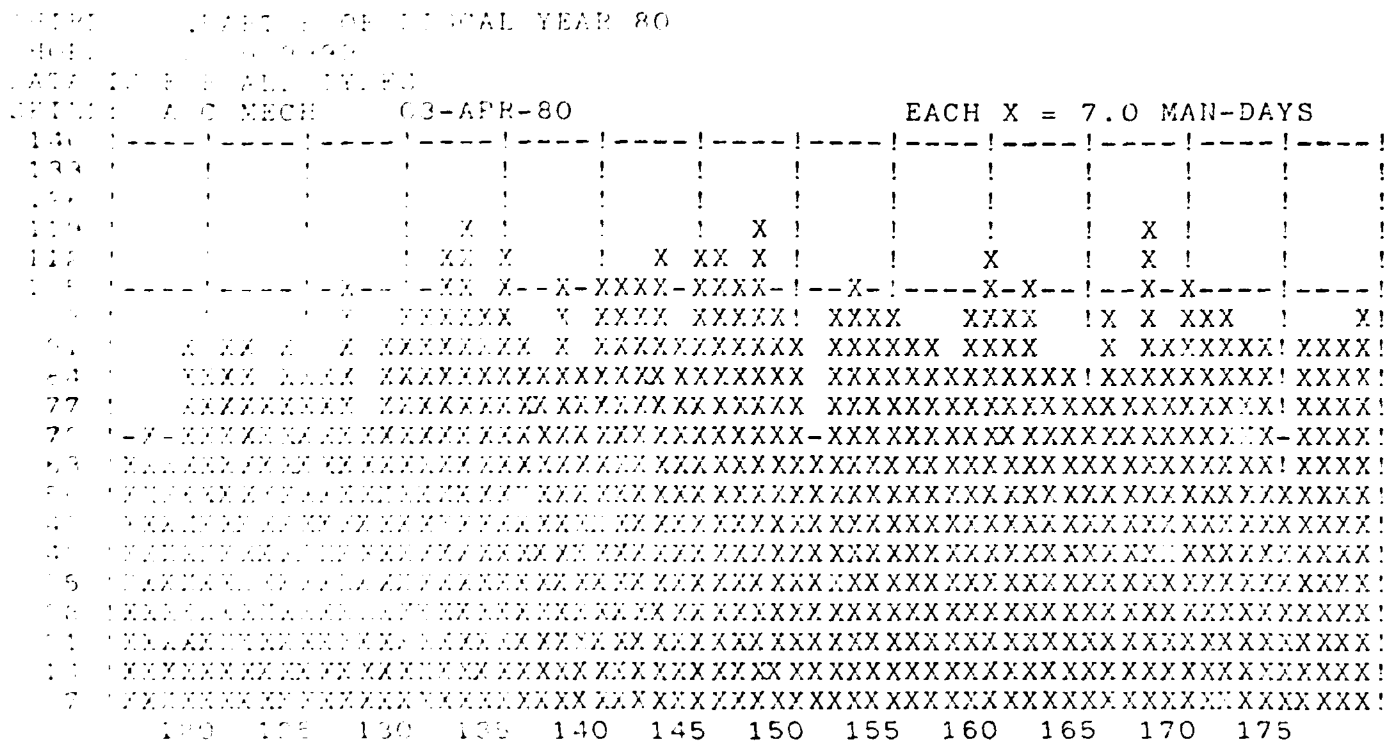

Figure 3.6 HISTOGRAM Showing Manpower Requirements for a Selected Trade Skill (Aircraft Mechanic) Produced by the PSKILL Program

a. One of the up to sixty trade skills considered by itself, or

b. Cumulation of all the trade skills combined.

(2) Hard-copy print out of the histograms displayed on the CRT, plus a tabulation of the daily requirements for:

a. One of the up to sixty trade skills (see figure 3.7), or

b. Cumulation of all sixty trade skills. When "all skills" and "hard copy" both are selected, the user is also provided with the tabulated values of the daily manhour requirements for each of the individual skills, given in man days. (See Figure 3.8) .

3.2.4.2.2 PSHOPS Program

The functions of the PSHOPS Program are similar to some of those of the PSKILL Program, except these apply to production shops rather than to trade skills. PSHOPS has the capability of providing both CRT and hard copy histogram displays; in this instance the data are available for any selected individual shop and for the accumulation of all shops. As in PSKILL, when the user requests a hard-copy of the histogram being viewed on the CRT he may also request a tabulation of manpower requirements for the selected shop. In addition, when the histogram represents the cumulation of all trade skills the user may request a hard-copy of a table of manpower requirements for each shop for each day. The format for this table is similar to that shown in Figure 3.8 for all skills.

A feature new to PSHOPS is a hard-copy print out that results when the user asks for a "Report." Figure 3.9 is an extract of such a report. The information provided is in the form of two columns. The

SKILL ALL SKIL 03-APR-80

WORK DAY	MAN-HOURS	CUM MAN-HOURS	MAN-DAYS
120	2693	2693	336 6
121	2572	5265	321 5
122	2725	7990	340 6
123	2554	10544	319 3
124	2313	12857	289 1
125	2478	15335	309 8
126	2375	17710	296 9
127	2382	20092	297 8
128	2511	22603	313 9
129	2604	25207	325 5
130	2578	27785	322 3
131	2550	30335	318 8
132	2591	32926	323 9
133	2729	35655	341 1
134	2692	38347	336 5
135	2471	40818	308 9
136	2487	43305	310 9
137	2448	45753	306 0
138	2404	48157	300 5
139	2386	50543	298 3
140	2542	53085	317 8
141	2675	55760	334 4
142	2642	58402	330 3
143	2836	61238	354 5
144	2738	63976	342 3
145	2607	66583	325 9
146	2774	69357	346 8
147	2406	71763	300 8
148	2382	74145	297 8
149	2523	76668	315 4
150	2467	79135	308 4
151	2508	81643	313 5
152	2508	84151	313 5
153	2499	86650	312 4
154	2512	89162	314 0
155	2420	91582	302 5
156	2447	94029	305 9
157	2250	96279	281 2
158	2386	98665	298 3
159	2129	100794	266 1
160	1935	102729	241 9
161	2034	104763	254 3
162	1971	106734	246 4
163	1943	108677	242 9
164	2065	110742	258 1
165	2199	112941	274 9
166	2087	115028	260 9
167	2223	117251	277 9
168	2187	119438	273 4
169	2035	121473	254 4
170	2292	123765	286 5
171	2199	125964	274 9
172	2146	128110	268 3
173	2303	130413	287 9
174	2230	132643	278 8
175	2216	134859	277 0
176	2372	137231	296 5
177	2512	139743	314 0
178	2494	142237	311 8
179	2559	144796	319 9
180	2467	147263	308 4
181	2360	149623	295 0
182	2497	152120	312 1
183	2162	154282	270 3

AVERAGE DAY= 2410 66   STANDARD DEVIATION= 215 40

Figure 3.7 Table of Manpower Requirements for Selected Trade Skills Produced by PSKILL Program

MAN-DAY USAGE BY WORK DAY (SHOPS 0 TO 9999)

WRK DAY	A/C ELEC	A/C MECH	BAND FEC	ELEC EQP	ELEC TRON	ELEC PLTR	ELCT TRON	ENG MECH	EQP CLNR	EQP MECH	FORK LIFT	GRAP HICS	GRND EQP	HEAT TRT	INST RMNT	MACH INST	MACH NTCL	PLSP LAST	MOLD ER	MTL INSP
1	20	46	1	0	0	2	12	1	47	0	0	0	0	0	3	4	2	1	0	3
2	[illegible]	43	1	0	0	2	11	1	[illegible]	0	0	0	0	0	2	3	1	1	0	3
3	18	62	1	0	0	2	12	1	33	0	0	0	0	0	3	4	2	1	0	3
4	27	95	1	0	0	2	11	1	33	0	0	0	0	0	3	4	2	1	0	3
5	26	81	1	0	0	2	11	1	47	0	0	0	0	0	3	4	2	1	0	4
6	27	63	1	0	0	2	11	1	[illegible]	0	0	0	0	0	2	4	2	1	0	4
7	28	91	1	0	0	2	12	1	51	0	0	0	0	0	2	4	2	1	0	4
8	24	74	1	0	0	2	13	1	[illegible]	0	0	0	0	0	3	4	2	1	0	4
9	28	92	1	0	0	2	13	1	35	0	0	0	0	0	3	4	2	1	0	4
10	25	84	1	0	0	2	13	1	33	0	0	0	0	0	3	4	2	1	0	4
11	25	64	1	0	0	2	14	2	40	0	0	0	0	0	3	4	2	1	0	4
12	32	[illegible]	1	0	0	2	[illegible]	1	[illegible]	0	0	0	0	0	3	4	2	1	0	4
13	24	75	1	0	0	[illegible]	[illegible]	1	[illegible]	0	0	0	0	0	3	5	2	1	0	4
14	27	92	1	0	0	3	13	1	47	0	0	0	0	0	3	4	2	1	0	3
15	28	95	1	0	0	3	14	2	47	0	0	0	0	0	3	4	2	1	0	3
16	[illegible]	97	1	0	0	2	13	1	[illegible]	0	0	0	0	0	3	4	2	1	0	3
17	[illegible]	114	1	0	0	[illegible]	[illegible]	1	[illegible]	0	0	0	0	0	3	4	2	1	0	[illegible]
18	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	3	4	2	1	0	3
19	[illegible]	[illegible]	1	0	0	[illegible]	[illegible]	1	[illegible]	0	0	0	0	0	3	3	2	1	0	[illegible]
20	[illegible]	[illegible]	1	0	[illegible]	3	[illegible]	1	[illegible]	0	0	0	0	0	3	4	2	1	0	[illegible]
21	25	92	1	0	0	3	13	1	[illegible]	0	0	0	0	0	3	4	2	1	0	3
22	24	87	1	0	0	3	[illegible]	1	[illegible]	0	0	0	0	0	3	4	2	1	0	3
23	33	105	1	0	0	3	[illegible]	1	[illegible]	0	0	0	0	0	3	4	2	1	0	3
24	26	[illegible]	1	0	0	3	12	1	26	0	0	0	0	0	3	4	2	1	0	3
25	32	103	1	0	0	2	11	1	[illegible]	0	0	0	0	0	3	4	2	1	0	3
26	31	[illegible]	1	0	0	2	10	1	[illegible]	0	0	0	0	0	2	3	2	0	0	3
27	33	103	1	0	0	2	11	1	45	0	0	0	0	0	3	4	2	1	0	3
28	32	107	1	0	0	2	13	1	43	0	0	0	0	0	2	4	2	1	0	3
29	[illegible]	[illegible]	1	0	0	2	12	1	35	0	0	0	0	0	3	4	2	1	0	3
30	32	[illegible]	1	0	0	[illegible]	13	1	[illegible]	0	0	0	0	0	2	4	2	1	0	3
31	32	[illegible]	1	0	0	2	[illegible]	1	24	0	0	0	0	0	2	3	1	1	0	2
32	32	[illegible]	1	0	0	2	[illegible]	1	[illegible]	0	0	0	0	0	2	2	1	[illegible]	[illegible]	2
33	[illegible]	[illegible]	1	0	0	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]	[illegible]	[illegible]	2
34	[illegible]	[illegible]	1	0	0	[illegible]	[illegible]	1	[illegible]	0	0	0	0	[illegible]	2	3	2	[illegible]	[illegible]	2
35	27	93	1	0	0	2	13	1	[illegible]	0	0	0	0	0	3	3	2	1	[illegible]	2
36	23	77	1	0	0	[illegible]	14	1	[illegible]	0	0	0	0	0	3	3	2	1	0	2
37	[illegible]	99	1	0	0	2	[illegible]	1	[illegible]	0	0	0	0	0	[illegible]	3	2	1	0	2
38	31	104	1	0	0	1	12	1	[illegible]	0	0	0	0	0	2	2	1	0	0	1
39	33	[illegible]	1	0	0	1	[illegible]	1	[illegible]	0	0	0	0	0	3	2	1	1	[illegible]	2
40	[illegible]	101	1	0	0	1	[illegible]	1	[illegible]	0	0	0	0	[illegible]	2	2	1	1	[illegible]	[illegible]
41	25	92	1	0	0	[illegible]	13	1	45	0	0	0	0	0	3	2	1	1	0	2
42	27	91	1	0	0	1	12	1	44	0	0	0	0	0	2	2	1	1	0	1
43	27	85	1	0	0	2	14	1	44	0	0	0	0	0	3	2	1	1	0	2
44	29	96	1	0	0	1	13	1	31	0	0	0	0	0	3	2	1	1	0	2
45	33	111	1	0	0	1	12	1	24	0	0	0	0	0	3	2	1	1	0	2
46	31	101	1	0	0	1	12	1	33	0	0	0	0	0	2	2	1	1	0	2
47	32	103	1	0	0	1	12	1	40	0	0	0	0	0	3	2	1	1	0	2
48	27	85	1	0	0	1	12	1	[illegible]	0	0	0	0	0	2	2	1	1	0	1
49	29	87	1	0	0	2	14	1	49	0	0	0	0	0	3	3	2	1	0	2
50	24	71	1	0	0	2	15	1	53	0	0	0	0	0	3	3	2	1	0	2
51	30	99	1	0	0	2	14	1	35	0	0	0	0	0	3	3	2	1	0	2
52	27	83	1	0	0	2	13	1	32	0	0	0	0	0	3	3	2	1	0	2
53	[illegible]	117	1	0	0	2	13	1	[illegible]	0	0	0	0	0	3	3	2	1	0	2
54	29	92	1	0	0	2	13	1	33	0	0	0	0	0	3	3	2	1	0	2
55	31	102	1	0	0	3	13	1	34	0	0	0	0	0	3	4	2	1	0	3
56	28	97	1	0	0	3	13	1	34	0	0	0	0	0	2	4	2	1	0	2

Figure 3.8 Extract From Table of Manpower Requirements Printed Out by the PSKILLS Program for Skills

SHOP MANHOUR USEAGE REPORT FROM DAY 57 TO DAY 120

SHOP NUMBER	MANHOURS
5	0
BRANCH TOT	0
100	0
BRANCH TOT	0
200	0
BRANCH TOT	0
300	0
380	0
BRANCH TOT	0
400	0
BRANCH TOT	0
500	0
512	2570
515	238
521	805
522	391
526	8953
BRANCH	12957
600	105
650	0
680	0
BRANCH TOT	105
800	223
BRANCH TOT	223
DIVIS. TOT	13285

Figure 3.9 A Segment of the Computer-Printed SHOP MANHOUR USEAGE REPORT Produced by the PSHOPS Program

first column contains the shop numbers, and the second the number of manhours required from the corresponding shop during the entire period of the time frame selected. It should be noted that Branch and Division subtotals are also provided.

3.2.4.2.3 <u>WORKERS Data File and LOADS Data File and Program</u>

Unlike the PSKILL Program, whose concept was initiated by the developer, the LOADS Program was originated entirely by the user. LOADS began as a program that could take two vectors of data representing manhour requirements for each of the production shops, one vector of "Direct labor hours" and another of "Indirect labor hours," over some time period implied by the user, and spread those hours over the different trade skills assigned to each of the shops. The result is a hard copy print out of a listing of the shops, one per line, with the remainder of each line containing the name of each trade skill assigned to that shop, and both the number of manhours required by that skill during the period and the average number of workers required to support those hours on an eight hour per employee-day basis. Figure 3.10 is an example of the report generated.

A separate report is generated for each of the direct and indirect labor hour vectors, and one is created for the sum of those two vectors which represents the total manhours required.

Each of the separate reports generated by PLOADS also includes a segment in the form of Figure 3.11. This portion of the report lists the trade skill names, the total hours required for each of the trades, the average number of workers required in each trade, the number of such workers currently available, the difference between number

```
TOTAL     MANHOUR REQ'S FOR EACH TRADE-SKILL IN EACH SHOP
DURING FISCAL YEAR 80    QUARTER 1
SHOP  HOURS      SERVICE TRADES AND HOURS
   5       0.    SERVCTRD      0 / 0 0
       -------
           0         BRANCH TOTAL

 100       0     SERVCTRD      0 / 0.0
       -------
           0         BRANCH TOTAL

 200       0.    SERVCTRD      0 / 0 0
       -------
           0.        BRANCH TOTAL

 200       0.    SERVCTRD      0. / 0.0
 300       0.    SERVCTRD      0 / 0 0
       -------
           0         BRANCH TOTAL

 400       0     SERVCTRD      0 / 0.0
       -------
           0.        BRANCH TOTAL

 500       0     SERVCTRD      0 / 0 0
 512       0     SERVCTRD      0. / 0.0
 515       0     SERVCTRD      0. / 0 0
 521       0     SERVCTRD      0. / 0 0
 522       0     SERVCTRD      0 / 0 0
 526       0     E AND E       0. / 0 0
       -------
           0.        BRANCH TOTAL

 600       0     SERVCTRD      0 / 0 0
 650       0     SERVCTRD      0 / 0 0
 690       0     SERVCTRD      0 / 0 0
       -------
           0         BRANCH TOTAL

 800       0     SERVCTRD      0 / 0 0
       -------
           0         BRANCH TOTAL

           0.        DIVISION TOTAL

3111  10529.     EQP CLNR  10529 /24 0
3112  16575.     EQP CLNR  16575 /37.8
3113   5301      ELECPLTR   3022 / 6 9    EQP CLNR  1113 / 2 5   SANDBLST  1166. / 2.7
3115   6487.     PAINTER    6487. /14 8
3116  22103      PAINTER   22103 /50 5
3151   2470.     PRES SVC   2470 / 5 6
3152   1233      PRES SVC   1233 / 2 8
3154  13133      PRES PRO  13133 /30 0
3155   1989      UPHOLSTR   1989 / 4 3
3155   1571.     ROOFER     1571 / 3 6
       -------
      81291          BRANCH TOTAL
```

Figure 3.10   Segment of the Trade Skill Manhours Spread Report Produced by the LOADS Program

DATE OF CALCULATIONS: 03-APR-80
TOTAL TRADE-SKILL HOURS REQUIRED FOR SHOPS IN RANGE FROM 5 TO 6510
HOURS PER WORKER DURING PERIOD 500
THIRD QUARTER OF FISCAL YEAR 80
ATTRITION PERIOD IS 4 MONTHS LONG

TRADE-SKILL NAME	TOTAL HOURS IN PERIOD	REQUIRED WORKERS	CURRENT WORKERS	DIFFERENCE IN WORKERS	ATTRITED WORKERS	ATTRITED DIFFERENCE	MONTHLY ATTRITION RATE
A/C ELEC	35221.	70.4	72	1.6	68	-2.4	0.013200
A/C MECH	66730	133.5	160	34.5	153	19.5	0.022967
BRNG REC	3083	6.2	7	0.8	7	0.8	0.000000
ELEC EQP	1974	3.9	5	1.1	5	1.1	0.000000
ELECTRCN	648.	1.3	2	0.7	2	0.7	0.000000
ELECPLTR	9808.	19.6	28	8.4	26	6.4	0.017542
ELECTRON	57847.	115.7	156	40.3	152	36.3	0.006603
ENG MECH	45396.	90.8	112	21.2	107	16.2	0.011808
EQP CLNR	29253	58.5	60	1.5	59	0.5	0.006175
EQP MECH	1290.	2.6	4	1.4	4	1.4	0.000000
FORKLIFT	509.	1.0	2	1.0	2	1.0	0.000000
GRAPHICS	1978.	4.0	3	-1.0	3	-1.0	0.033333
GRND EQP	1822.	3.6	4	0.4	4	0.4	0.000000
HEAT TRT	615.	1.6	3	1.4	3	1.4	0.000000
INSTRMNT	25514.	53.0	59	6.0	58	5.0	0.005708
MACHINST	20052	40.1	56	15.9	55	14.9	0.002733
MACHNTLL	9471.	18.9	18	-0.9	15	-3.9	0.041667
MLDPLAST	608	1.2	3	1.8	3	1.8	0.000000
MOLDER	530.	1.1	1	-0.1	1	-0.1	0.041667
MTL INSP	7947.	15.9	13	-2.9	12	-3.9	0.0119[illegible]
MILLING	1932.	3.9	7	3.1	7	3.1	0.000000
ORDNANCE	17190.	34.4	25	-9.4	24	-10.4	0.008067
OXY MECH	4116	8.2	4	-4.2	4	-4.2	0.000000
PAINTER	31118.	62.2	65	2.8	64	1.8	0.005283
PATRNMKR	599	1.2	0	-1.2	0	-1.2	0.000000
PIPE FIT	602.	1.2	1	-0.2	1	-0.2	0.000000
PLSTFIBR	4222	8.4	8	-0.4	7	-1.4	0.025008
PNE MECH	22048	44.1	64	19.9	62	17.9	0.008059
PRES FAB	12092	24.2	20	-4.2	19	-5.2	0.012500
PRES SVC	5273	10.5	13	2.5	12	1.5	0.019233
PROP MECH	796	1.6	3	1.4	3	1.4	0.027775
PWRS.PRT	8502.	17.0	20	3.0	19	2.0	0.015075
RIGGER	608	1.4	1	-0.4	1	-0.4	0.000000
RUBBER	1164	2.3	4	1.7	4	1.7	0.000000
SHEETMTL	66246	132.5	164	31.5	154	21.5	0.016650
SHIP FIT	645.	1.3	0	-1.3	0	-1.3	0.000000
SHOTPEEN	1711.	3.4	6	2.6	6	2.6	0.000000
SANDBLST	2415.	4.8	7	2.2	7	2.2	0.000000
SERVCTRD	0	0.0	0	0.0	0	0.0	0.000000
TOOLSHND	0.	0.0	1	1.0	1	1.0	0.000000
TOOLMAKR	5751.	11.5	13	1.5	13	1.5	0.006408
TRONMEAS	41337.	82.7	82	-0.7	81	-1.7	0.003167
TRON SYS	3900.	7.8	13	5.2	12	4.2	0.022225
UPHOLSTR	1511.	3.0	5	2.0	5	2.0	0.000000
WELDER	6822.	13.6	24	10.4	23	9.4	0.012500
FOREMAN	34061.	68.1	79	10.9	75	6.9	0.013158
E AND E	0.	0.0	0	0.0	0	0.0	0.000000
P/C ELEC	3717.	7.4	6	-1.4	6	-1.4	0.000000
P/C MECH	4248.	8.5	3	-5.5	3	-5.5	0.027775
	604191.	1208.4	1414	205.6	1352	143.6	0.008928

Figure 3.11 Example of the Trade Skill Workers Required Report Produced by the LOADS Program

available and the number required, and data concerning the attrition predicted for those workers between the current time and the time frame on which the report is based.

This program has grown considerably from its original conception to one that is far more powerful. The users were becoming hooked on the application of computer-based systems to their daily tasks. The users first decided that the hours represented by the requirements vectors would represent periods of different lengths, in particular both quarters and months. The number of records to be stored was increased to three per quarter for twelve quarters, one per month for twelve months, and then three per year for three years, with the system summing the quarterly records together to create those for a given year.

The next major enhancement was the creation of monthly and quarterly records by the PSHOPS program, and storing those records in the file accessed by the PLOADS program, thereby allowing the creation of a trade skill spread report by shops for the hours generated as a result of the current induction schedule. It is easy to envision that ultimately all of the records utilized by the PLOADS program will be generated as a result of induction schedules for aircraft, engines, etc.

3.3 Schedule Development System

Prior to proceeding with a description of the portion of this project which develops schedules for the user, it is worthwhile to take a more in-depth look into the complexity of the problem.

In the discussion of the concept of a flowshop in Chapter 1 one important factor was mentioned only in passing. That factor is the

one where in the usual definition of a flowshop one considers that only one task can be in a given phase at any one time; i.e. only one machine of each type exists, and that there is no passing of jobs; i.e. the order in which jobs finish is the same as that in which they start.

The majority of the research into the flowshop scheduling problem has been done for systems that incorporate such no-passing limitations, and in particular with a view toward the objective of 'minimizing makespan,' where makespan is defined as the time when all of the scheduled tasks are completed. For example, in 1967 Gupta described flowshop scheduling as follows:

"Given n jobs to be processed on M machines, the process time of job i on machine j, defined as t_{ij}, (i=1,2, ..., n; j=1,2, ..., M), the problem is to find that ordering of jobs which minimizes total process time or make-span" [11].

In that, and subsequent papers, Gupta described a "Lexicographic Search" for solution of the problems which could be fit to such a narrowly defined mold [12] [13].

In a July, 1977, article, Dannenbring published "An Evaluation of Flowshop Sequencing Heuristics" [5] wherein he discusses the concepts underlying eleven different flowshop scheduling heuristics. The evaluations contained therein were limited to minimizing the maximum makespan as an objective. His study, however, does attempt to expand the problem size beyond the three or four jobs and three or four machines considered in the majority of other papers. Still though, he does not discuss the problem of a generalized flowshop, nor one where there is a continuum of input tasks over time.

Further research into literature on the subject shows the similarity of other efforts with respect to the objective of minimizing makespan, sometimes referred to as Johnson's criterion. Gupta [11] and Manne [21] have written on the relationship of this objective to that of an economist desiring to reduce costs in terms of dollars. The claim is that there is an excellent correlation between minimum makespan and minimum dollar costs. Most of the heuristics described in the literature, for the makespan objective, are not applicable to the problem of leveling the resource requirements for a production system, particularly one where the input of tasks continues over time. Gupta's article [11] divides the theoretical developments in flowshop scheduling under the no-passing, minimize makespan assumptions into the following three categories:

(a) Combinatorial analysis,

(b) Branch-and-Bound procedures, and

(c) Lexicographic Search

The first of these appears to have little application to large-scale problems such as this paper discusses. Branch-and-bound techniques also are not applicable because resource leveling requires one to complete an entire schedule to the bottom of the tree in order to determine the leveling measure for resource requirements per unit of time. Lexicographic search is precluded for the same reason as branch and bound. Most of the heuristics in the Dannenbring article [5] fail for similar reasons, however, he discusses a set of heuristics, suggested by Page [22] [23], related to computer sorting, which appeared to have merit in application to a generalized flowshop; namely the individual and group exchanging heuristics. Derivations of these

methods have been applied in this instance, and are discussed in later sections.

One important facet of the complexity of finding a computer solution method for the production scheduling problem is not widely discussed in the literature, if at all. This is the determination by a system developer of the criteria by which the user will judge the acceptability of schedules produced by the machine. During the early stages of plant level research, the developer spent numerous hours with the individuals who have been creating the schedules over the past few years. In spite of these efforts, the first schedules produced by the computer were totally unacceptable to the user, either because some criteria had been overlooked or misunderstood by the developer, or else not provided by the user. The latter possibility could possibly result from a perceived or subliminal apprehension of the machine as a threat to the schedulers themselves.

One example of such an occurrence might be enlightening to the reader. The initial schedules developed by the computer contained subsets that consisted of consecutive inductions of similar product types (products from the same macro group). The schedulers claimed that such a schedule would cause excessive swings in the work loads for certain segments of the production system. Whether or not this was in fact true was immaterial to the discussion. What such schedules did do in reality was to violate a premise that the schedulers had been using in the past. At that stage in the development it was best to accept their reservations as reasonable and to proceed with the incorporation of limitations into the computer programs which would prevent such sequential scheduling strings, or at least to suppress them in the

initial stages of schedule creation and to allow their entry only when such scheduling "anomolies" would in fact create an improvement in the schedule's measurement of effectiveness. The element labeled UNIFORM Program in the lower right hand corner of Figure 3.12 includes such perceived constraints into the computer system.

Throughout the latter stages of the evolutionary development of the management information system, the design and creation of the Schedule Development System portion of this project was taking place. Figure 3.12 shows the entire, elemental structure of this System. It should be noted that five of the elements depicted are those that link the two systems. The POINTER Data file contains the constants that are germane to both systems. In addition, this file is used to hold a vector (record) that is primarily used in the creation of new schedules for future periods. The SHOP and SKILL Data files are used as the source of information on the utilization of critical resources by products that are scheduled for overhaul. The SCHEDULE Data file contains the current "real" schedule for a two year and eighty day period. When a satisfactory new schedule has been developed, it is made into the "real" schedule by copying the new schedule into the SCHEDULE Data file.

3.3.1 Criticality of Resources

The first major problem in the creation of production schedules for this generalized flowshop was that of determining the user's objective. In this instance the stated objective at the beginning of development was one of "leveling out the daily manhour requirements for the critical trade skills." It is obvious that an objective stated thusly is one which involves multiple optimizing criteria. The execution time requirements

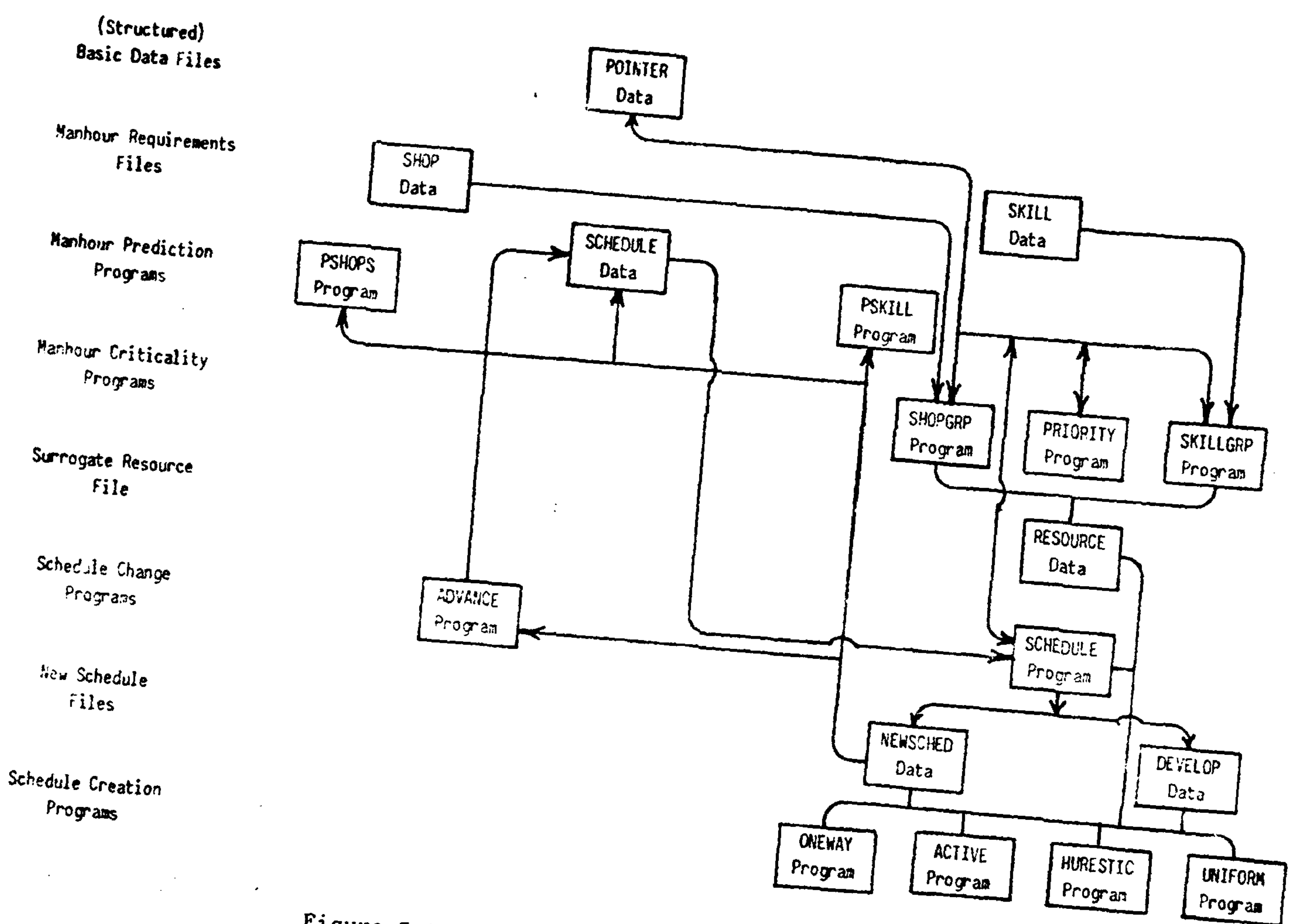

Figure 3.12 Structure of the SCHEDULE DEVELOPMENT SYSTEM

for any of the known approaches to multiple criteria are far too excessive for direct application to an interactive system, especially when the system is planned for installation on a small computer. The direction taken in this case was through the creation of surrogates for the criteria, through selection of certain trade skills as critical, and then to develop and improve schedules based upon these surrogates. An alternate approach through the leveling of manhour requirements for groups of production shops, through cumulation of their hours, was considered and programmed into the system.

Two programs, PRIORITY and SKILLGRP shown on the right side of Figure 3.12, are used to select the five trade skills which are designated as critical and to create a file containing the manhour requirements vectors for those five skills. The program named SHOPGRP performs both of these tasks for the shop groups mentioned above.

3.3.2 Creation of Initial Proposed Schedules

The SCHEDULE Program is utilized to input all of the specifications necessary for the creation of an induction schedule for some future period. Such data includes:

(a) Beginning and ending dates for the period,

(b) Number of products of each type to be scheduled during the period,

(c) Prescheduling of any products whose induction dates are fixed for some reason,

(d) Selection of the desired resource group for leveling,

(e) Verification of the correctness of the resource priority sequence, and

(f) Review of the status of nonstandard products already scheduled during the selected scheduling horizon.

After accepting the input of such data the SCHEDULE Program must create the following records for inclusion in the DEVELOP Data file:

(a) Prescheduled schedule, and

(b) Daily requirements records for the selected resources for two periods:

(1) Selected scheduling period, resulting from runout of products in process prior to the period, and

(2) Quarter subsequent to the scheduling period, based upon some prediction of the products that will be inducted in the future.

The next phase in the creation of a set of proposed initial schedules, one of which will be selected as a starting point for the creation of a final schedule, is the execution of the UNIFORM Program. This program is an automation of the methods whereby schedules had been created by hand in the past. Two sound reasons for the creation of such a program exist. First and foremost it is a confidence builder. When the computer can create a schedule which, although not identical, is humanly indistinguishable from one created by hand for the same period, it is difficult for the user to say that the system is unacceptable for creating schedules. Second, a developer may safely assume that the people who have been creating schedules for some time have learned a great deal about the system being scheduled and the requirements of such schedules. When the developer can automate such a system, it is highly likely that he or she has created a sound understanding of the system and thereby increased the likelihood of success.

It took three iterations of the feedback loop for the program UNIFORM to satisfy the criteria in the preceeding paragraph. In

addition, the results from this program have provided excellent schedules for use as a starting point in the creation of final schedules. This fact will be borne out in the subsequent chapter which compares the results of hand-made and computer-created schedules.

The programs named HURESTIC (sic) and ACTIVE each create a set of nine or ten schedules that are available for selection as the one used as a starting point. HURESTIC creates nine schedules based upon a "maximize the minimum day/ maximum day ratio" for one of the five critical resources (skills or shops), or a summation of the first n most critical resources for n=2,3,4,5, where the summation is a vector summation of the daily requirements. The creation of a tenth schedule by the HURESTIC Program is optional for the user. Should the user choose, he or she may interact in the creation of a schedule that is based upon leveling of the cumulation of the five critical resources. Figure 3.13 shows the CRT display created by the system for use in developing such a schedule. The contents of this display include the manhour requirements of a partial schedule for the current scheduling horizon and the runout from the preceeding period shown as capital O's, the predicted requirements for the subsequent quarter shown as capital F's, and the profile of the requirements for the type to be added to the schedule shown as capital A's. Other scheduling data are shown in the top two lines, and the third line displays the elements currently in the schedule. The bottom line displays the options available to the user. These include:

(a) Schedule the type shown in the first line on the day indicated by the + in the third line, or

(b) Move the current type to the left or right by the desired number of days, or

(c) Change to a different type of product and then return to (a).

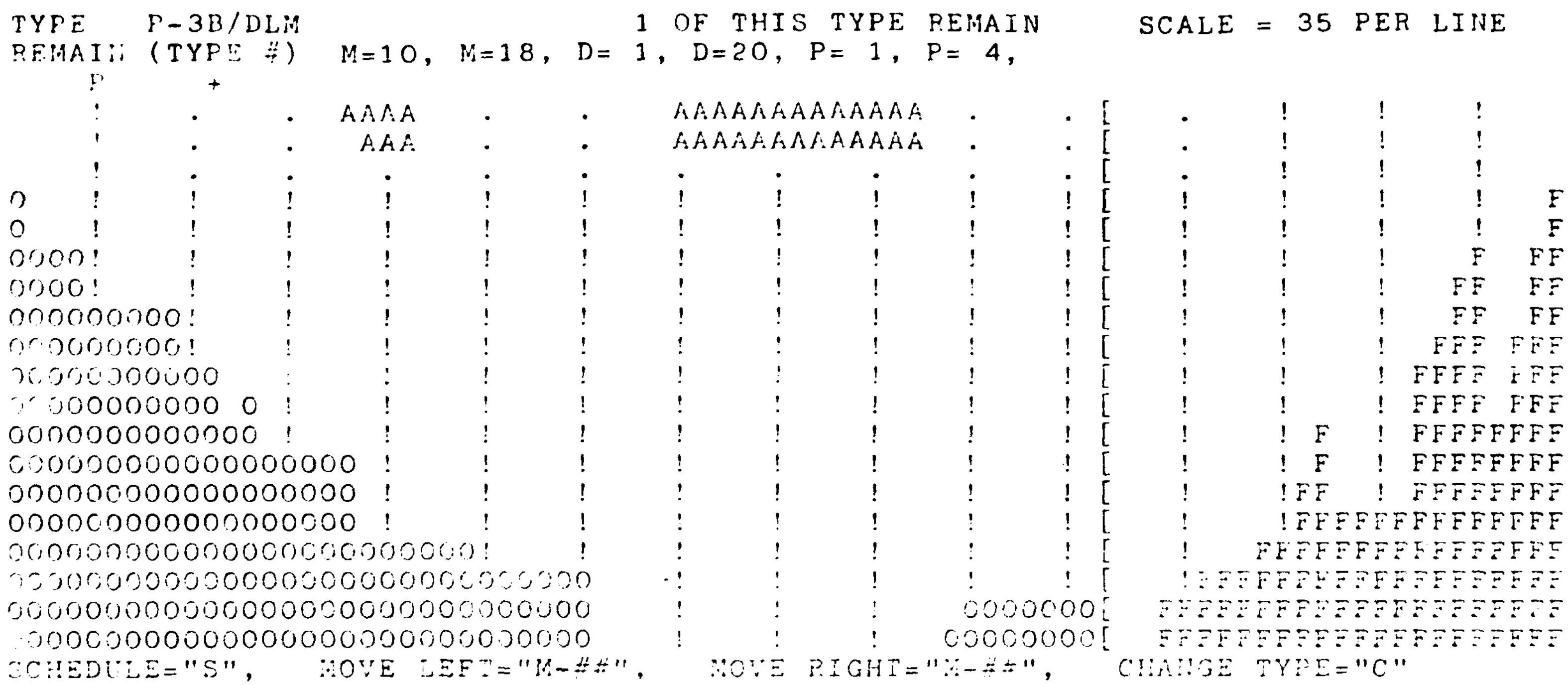

Figure 3.13 CRT Display of the Partial Schedule Resource Requirements Provided During the Execution of the ACTIVE and HURESTIC Programs

The creation of a schedule in this fashion is fairly time consuming, and it is not anticipated that this method will be widely used in the future. However, this segment of the program is another valuable tool in the creation of confidence in the user; this time by allowing him to see a visual representation of the kinds of effects the addition, deletion, or moving of a single product induction date may have on the schedule. This increases the user's understanding of the system, thereby increasing his or her confidence and appreciation for the complexity of the leveling problem.

The ACTIVE Program creates the first nine schedules of the HURESTIC Program; however, it creates all nine of them in the same fashion as the optional active segment of the HURESTIC Program. ACTIVE was developed in an attempt to improve on the schedules created by hueristic methods. In some instances there was an improvement, but the time required on the user's part is excessive and this program will undoubtedly disappear from the final version. Its retention at this point is primarily one of increasing the user's understanding of the large number of schedules which are considered and discarded by the computer during the creation of the initial proposed schedules.

3.3.2 Creation of the Final Schedule

The program segment shown in Figure 3.12 which bears the name ONEWAY is used to select the desired starting schedule from those created by UNIFORM and HURESTIC, and then to run an exhaustive series of one-way interchanges of the elements in that schedule in an attempt to make improvements thereon. The ONEWAY program starts

out by allowing the user to choose the desired starting-point schedule. It then allows the choice of remaining interactive, or switching to a passive mode, whereby the system is allowed to continue its search through the one-way interchanges in an uninterrupted fashion. The user is then provided with the following list of choices for the optimizing criteria by which alternative schedules are to be compared during the search:

(a) Unweighted

(1) Maximize the sum of minimum days, or

(2) Maximize the sum of minimum/average ratios, or

(3) Maximize the sum of minimum/maximum ratios, or

(4) Minimize the sum of standard deviations, or

(5) Maximize the sum of average/standard devation ratios, or

(b) Weighted (by trade skill priority):

(6) Maximize the sum of minimum days, or

(7) Maximize the sum of minimum/average ratios, or

(8) Maximize the sum of minimum/maximum ratios, or

(9) Minimize the sum of standard deviations, or

(10) Maximize the sum of average/standard deviation ratios.

It should be noted at this point that the schedule evaluations are based upon the predicted daily manhour requirements that would accrue to each of the five most critical trade-skills. In addition, the number of days considered in the comparison between schedules is set at the number in the quarter being scheduled plus sixty-six; the extra days being added to reduce edge effects that could result from using too short of a period.

The final choice provided to the user prior to the commencement of the search is that of the initial schedule, selected from the eleven created by the UNIFORM and HURESTIC programs.

CHAPTER 4

TESTING AND ANALYSIS OF THE SCHEDULING SYSTEM

4.1 Abandoned Aspects of the System

The reader can well imagine that many of the ideas generated for inclusion in this system have turned out to be less than desired, if not less than useful. Still their inclusion in this paper is valuable as a possible guideline to others who may someday attempt to solve other problems with similar facets.

The major program segment that has been abandoned is that one known as ACTIVE. In fact, it was an idea generated solely by the developer and was never evaluated by the user. The program turned out to be more time consuming in execution than could be justified by the results. The schedules proposed as a result of its execution were seldom better than those created by either the UNIFORM or the HURESTIC programs. In spite of this system's demise, it did serve a useful function. It provided a basis for the segment of the HURESTIC program which is used to create a single proposed schedule in an active fashion, and this segment has served to further educate the user on the complexity of creating a schedule whose objective is to level the daily manhour requirements. In fact, the educational value of the active segment of HURESTIC may well be that segment's only saving grace.

Another portion of the system which, although not abandoned, has fallen into disuse is the consideration of production shop groupings as a basis for the creation of induction schedules. This desuetude is partly because of the lack of time to fully evaluate its merits in an exploratory [illegible] involving the user.

4.2 Measurements of Effectiveness

The development, and acceptance by the user, of criteria by which schedule creation methods may be compared for effectiveness has been a difficult task. The reader may recall that the user's stated objective was "level the daily manhour requirements for critical trade skills." This led the developer to ask: "Given two different schedules for the same period of time how would you determine which was the best?" The user's response was: "Given that both were feasible and acceptable (?) then the one that did the best job of leveling the requirements for the cirtical trade skills." And so on, ad infinitum; a classic example of the difficulty of communications between user and developer.

One should note at this point that there are two separate and distinct facets to the problem of effectiveness measurement. The first is the measurement whereby the computer, during a series of one-way interchanges, chooses between two different schedules for the same period of time in order to find the one which does the best job of "leveling the critical trade skill requirements." The other is that whereby the user and developer can agree on two items:

(a) The computer does, or does not, produce better schedules than those that have been created by hand, and

(b) Given an affirmative agreement to the first item, which of the choices from the list of ten alternatives at the end of the last chapter is the best for use in creation of schedules during the one-way interchange operation.

In the case of the first item, the following is an example of the problem of agreement on the capability of the computer to create better schedules. From the developer's point of view the problem is conceptually fairly simple. One can perform a Student's t-Score test on the pairwise difference in standard deviations for the trade skills that

occurs between the hand-created schedules for the two years in the data base versus the schedules created for the same periods by the one-way interchange algorithm. For the users in this instance, and probably generally true in most instances, Student's t-Scores are rather nebulous and do have any direct, discernible relationship to the kinds of problems they face in the every-day facets of their production scheduling roles. The user's choice for a measurement tool would have manhours or dollars as a unit.

Further discussions on this subject are included later in this chapter.

4.3 Acceptability of the UNIFORM Schedule

Before proceeding into the tangled thicket of comparing the methods for the creation of schedules with respect to their overall ability to level the daily manhour requirements, it is worthwhile to take a short excursion into another facet of gaining acceptance for the entire schedule development system; in this instance demonstrating the acceptability of at least one of the starting-point schedule choices to the system user.

As stated in Chapter 3, the UNIFORM program creates a proposed induction schedule through automation of the same methods and criteria which have been used for the hand creation of schedules during past years. After three iterations of this program through the two-way feedback loop, it appeared that the program, to all intents and purposes, was able to successfully imitate the hand-created schedules. The developer's hypothesis became that the user could not distinguish between the two schedule sources, UNIFORM or hand, in spite of the

fact that the two schedules were considerably different for each of the quarters. An experiment was designed to test this hypothesis.

The experiment consisted of creating schedules for the six coming quarters. Current and previous schedules were not considered due to familiarity that the user might have with any idiosyncracies they contain. The user, hand-created schedules were also printed by the computer for the same six quarters. Both the hand and UNIFORM created schedules were printed in the same fashion in order to remove external clues as to their origin. Supervisory personnel were then given the two schedules for the same quarter and asked to identify the one created by hand. Five user personnel who work with the induction schedules on a daily basis were tested. Each was given the paired schedules in a different order for the six quarters. In addition some of the user personnel, in particular those who would be most familiar with the schedules, were given the paired schedules for all six quarters a second time, this time in an alternate order by quarters. The results were as follows:

$n = 42$ paired quarters

$x = 20$ incorrect choices (chose UNIFORM as hand-created)

H_o: $p_o = .5$, (P_o = hypothesized probability that user would err in selection)

H_a: $p_o \neq .5$

Test statistic:

$$Z = \frac{\hat{p} - p_o}{\sqrt{\hat{p}(1-\hat{p})/n}} = \frac{20/42 - .5}{\sqrt{(20/42)(22/42)/42}}$$

$$= -0.309$$

Rejection region: $Z > 1.96$

Conclusions:

Cannot reject H_0

95% Confidence interval for $p = (0.349, 0.651)$

In simple terms for the user, these data were "statistically significant evidence that the UNIFORM schedules were indistinguishable from the hand-created schedules when compared with respect to general appearance on a one-for-one basis." The result, added confidence on the part of the user that the system could in fact create acceptable schedules.

4.4 Analysis During the Creation of a Schedule

The program execution sequence during the development of a schedule is SCHEDULE, UNIFORM, HURESTIC, ONEWAY. There are three choices which must be made by the user during this sequence. At the beginning of the HURESTIC program the user must choose whether or not to create a proposed starting schedule actively; i.e. the tenth possible schedule created by HURESTIC. Then at the beginning of ONEWAY the user must first select the schedule to be used as a starting point and then select the optimization criteria from the list of ten choices described at the end of Chapter 3.

The choice of whether or not to create a schedule actively will be a personal choice on the part of the user. It is anticipated that this choice will generally be one of opting not to create such a schedule. In fact, as will be shown later, it is likely that the entire HURESTIC program will fall into disuse because it generally has not created schedule choices that are significantly better than the one created by

the UNIFORM program, especially when one considers the computer execution time required by the HURESTIC program.

The user is aided in his selection of the starting point schedule by the data provided by the computer at the end of the HURESTIC program, data that rank the ten or eleven proposed schedules in three ways. Figure 4.1 shows an example of the data on the ranking of the schedules based upon the minimum and maximum daily requirements, after being three-day running averaged, for the five critical trade skills. Figure 4.2 is an example of data for ranking the schedules based upon an unweighted quotient of mean divided by the standard deviation; a value referred to hereinafter as the "Mean Deviation." Figure 4.3 is an example for ranking the schedules based upon a weighted mean deviation for the five trade skills. In this instance the weights are 10 minus the trade skill priority, where the most critical of the five trade skills has a priority of 1 and the least critical of the five has a priority of 5.

The basic criteria by which these three rankings are created consists of either the minimum/maximum ratios or the mean deviations. The first of these is a surrogate for a three-standard-deviation measurement. The problem is not one of simply selecting a schedule based upon either a minimum-maximum ratio or mean deviation ranking. Combinatorially, the number of choices for ranking expands as a result of compounding factors such as:

(a) Which trade skill, or combination of trade skills, should be used in the ranking, and

(b) Should the rankings be weighted, and

THE FOLLOWING DATA IS FOR THE SECOND QUARTER OF FY 81

RELATIVE RANKINGS OF THE INITIAL SCHEDULES BASED UPON MIN/MAX RATIOS

TRADE SKILLS	SCHEDULES INDIVIDUALLY LEVELED FOR					SCHEDULES CUMULATIVELY LEVELED FOR					UNIFORMLY DISTRIBUTED SCHEDULE
	1 SKILLS	2 SKILLS	3 SKILLS	4 SKILLS	5 SKILLS	1 SKILLS	2 SKILLS	3 SKILLS	4 SKILLS	5 SKILLS	
1. SHEETMTL	3	5	7	1	4	9	8	10	6	11	2
2. A/C MECH	5	2	6	4	3	7	9	10	8	11	1
3. PAINTER	10	5	2	9	7	6	1	3	3	11	4
4. A/C ELEC	5	2	6	3	4	9	10	7	8	11	1
5. ELECTRON	10	4	9	1	3	5	6	7	8	11	2
RANKING OF SCHEDULES	6	2	5	3	4	8	7	9	10	11	1

Figure 4.1 Relative Rankings of the Proposed Starting Schedules Based Upon the MINIMUM/MAXIMUM Values

RATIOS OF (AVERAGE DAILY REQUIREMENT) / (STANDARD DEVIATION)

	INDIVIDUAL					CUMULATIVE					
	1	2	3	4	5	6	7	8	9	10	11
1	6.21	6.07	3.69	5.57	5.34	4.37	3.80	3.78	4.64	0.00	5.99
2	5.06	7.56	3.86	6.35	6.63	2.56	2.15	2.03	2.12	0.00	9.12
3	2.98	3.15	4.02	2.92	3.25	3.11	3.45	3.29	3.09	0.00	4.21
4	5.56	8.62	4.18	9.21	7.58	2.88	3.28	3.22	3.38	0.00	9.98
5	3.52	5.60	2.59	6.69	5.96	4.69	4.98	4.46	4.43	0.00	5.96
	23.32	31.00	18.33	31.01	28.77	17.61	17.66	16.79	17.66	0.00	35.25

NOTE: LARGER VALUES INDICATE A BETTER RESULT

RELATIVE RANKING OF THE SCHEDULES BASED UPON THE SUMMATION OF THE
(AVERAGE DAILY REQUIREMENT) / (STANDARD DEVIATION) RATIO SUMS FOR THE FIVE RESOURCES

5	3	6	2	4	9	8	10	7	11	1

Figure 4.2 Relative Ranking of the Proposed Starting Schedules Based Upon the AVERAGE/STANDARD DEVIATION Values

RELATIVE RANKINGS OF THE INITIAL SCHEDULES FOR WEIGHTED STANDARD DEVIATIONS

SCHEDULE NUMBER	1	2	3	4	5	6	7	8	9	10	11
	SCHEDULES INDIVIDUALLY LEVELED FOR					SCHEDULES CUMULATIVELY LEVELED FOR					UNIFORMLY
TRADE SKILL	1 SKILLS	2 SKILLS	3 SKILLS	4 SKILLS	5 SKILLS	1 SKILLS	2 SKILLS	3 SKILLS	4 SKILLS	5 SKILLS	DISTRIBUTED SCHEDULE
1. SHEETMTL	1	2	10	4	5	7	8	9	6	11	3
2. A/C MECH	5	2	6	4	3	7	8	10	9	11	1
3. PAINTER	9	6	2	10	5	7	3	4	8	11	1
4. A/C ELEC	5	3	6	2	4	10	8	9	7	11	1
5. ELECTRON	9	4	10	1	3	6	5	7	8	11	2
RANKING OF SCHEDULES	5	3	7	2	4	9	6	10	8	11	1

Figure 4.3 Relative Ranking of the Proposed Starting Schedules Based Upon the Weighted Standard Deviations (MEAN DEVIATIONS)

(c) If the rankings are weighted, should the weights be determined by:

(1) Order of trade skill criticality, or
(2) Mean values for daily requirements, or
(3) Some other weighting scheme?

The choices in the system as developed were:

(a) Combine all trade skills in the rankings, then

(b) Present an unweighted ranking for min/max ratios, and one for mean deviations, and

(c) Present a weighted ranking based on the order of trade skill criticality for the mean deviations.

4.4.1 Effectiveness of the UNIFORM Schedule

The next consideration of interest deals with the measure of effectiveness of the UNIFORM program schedules with respect to leveling the manhour requirements for critical trade skills. These measures can be compared in three ways:

(a) With respect to the other nine or ten schedules, created by the HURESTIC program, which are proposed as possible starting schedules,

(b) With respect to the hand created schedules, and

(c) With respect to the schedules that result after execution of the ONEWAY interchange program.

4.4.2 UNIFORM Versus HURESTIC Schedules

In general, the UNIFORM schedules created were better than the best of the nine or ten HURESTIC schedules. Since there are two full years in the schedule base, the opportunity to test schedules based upon real product-mix requirements was limited to eight one-quarter attempts. In six of those eight attempts the UNIFORM schedule was superior to all of the HURESTIC schedules by all the minimum-maximum

and mean deviation measurement rankings. For the other two quarters, the UNIFORM schedules ranked 2 and 4 in the mean deviation measurements, and 2 and 3 in the minimum-maximum measure. It is worth noting that these measures do not reflect the impact of the proposed schedules on skills other than the five designated as critical, nor do they reflect their impact on the daily manhour requirements for individual production shops. No t-score tests of UNIFORM versus HURESTIC schedules were made.

A comparison of the effectiveness of the UNIFORM versus the hand-created schedules and the UNIFORM versus those created by the ONEWAY program will follow a discussion of the statistical tests utilized in such comparisons.

4.5 Comparison of Schedule Creation Methods

The major divergence between the comparison of two alternative schedules during the creation of schedules, and the difference between the methods for creating schedules is tied up in the fact that the methods utilized during creation must be repeated continuously during such creation, while those used to compare creation methods are required only during an overall evaluation of the soundness of the system. The methods utilized during creation must be simple and rapid in execution, while those utilized to compare methods can be more sophisticated and involve a far greater number of computations. For example, it is all well and good to make use of Student's t-Scores to compare methods, while their use to compare alternative schedules during interchange would create execution times that would be far too

excessive. In a similar vein, one might use three or four different criteria to compare methods, but any similar attempt to determine whether or not an interchange should be made could lead to an ambiguity whose solution set would not be well defined and, therefore, extremely difficult to program. These factors explain the vast divergence between the methods for ranking the ten or eleven schedules that are proposed as possible starting points, or those underlying the list of ten optimization criteria choices provided to the user at the beginning of execution of the ONEWAY interchange program, and the methods described below for the comparison of schedule creation methods.

4.5.1 Criteria for Comparison of Schedule Creation Methods

All comparisons of schedule creation methods reported below have been accomplished through utilization of Student's t-Scores based upon one-tailed tests at an α level of less than 0.025. In each such test the evaluation consisted of a statistical analysis of the pairwise difference in manhour requirements between two schedules created by different methods. Three different tests were performed for each pairwise analysis: all trade skills, critical trade skills only, and all production shops.

Since the product mix for this aircraft overhaul system varies widely from quarter to quarter, and the creation of future schedules is done on a quarterly basis, the statistics evaluated consisted of pairwise differences between the schedules created by two different methods for the eight one-quarter time periods in the two year schedule. For example, an individual pairwise difference used as one sample in a

t-test might consist of the difference in standard deviations of the manhour requirements for the aircraft mechanic trade skill during the first quarter of fiscal year eighty-one when one standard deviation value results for the schedule created by hand, and the other value results for a schedule created by a series of one-way interchanges that attempt to minimize the sum of standard deviations for all five critical trade skills over that quarter.

For all of the t-tests described later, the test hypotheses were of the form:

H_o : $X_a - X_o \leq 0$, versus

H_a : $X_a - X_o > 0$, where

X_a : Statistic of interest for schedule created by method a, and

X_o : Corresponding statistic of interest for schedule created by method o.

Test statistic : $t = n(D/s_D)$, when

D : Average pairwise difference,

s_D: Standard deviation of differences,

n : Number of differences in test.

Rejection region : $t \geq t_{.0227,n-1} = 2.0$, for $n > 30$

The statistics of interest covered by these tests included:

(a) Statistics not normalized:

(1) Standard Deviation (Std Dev), and

(2) Maximum one-day requirement minus minimum one-day requirement (Max-Min).

(b) Statistics normalized through division by the mean:

(1) Mean Deviation (Mean Dev), an inverse of the coefficient of variation, and

(2) Maximum minus minimum difference divided by the mean (Dif/Mean).

Paired difference t-Scores for these four statistics were calculated for the critical trade skills considered alone, for all of the trade skills whose mean daily manhour requirement exceeded 1.0 hour, and for all of the production shops whose mean daily manhour requirement exceeded 1.0 hour.

4.5.2 Statistical Comparison of Schedule Creation Methods

The sections which immediately follow will discuss the results of a series of comparisons made to determine the "best" method for the creation of aircraft induction schedules for this overhaul facility. The conclusions based upon these results will be presented in the next chapter.

4.5.2.1 UNIFORM Versus Hand-Created Schedules

In general, the UNIFORM schedules are superior to those created by hand with respect to all of the trade skills and to all of the production shops; however, they are not significantly better when one considers only the five critical trade skills. Table 4.1 shows the t-scores resulting from twelve pairwise difference tests for the two methods.

In view of the fact that the rules for constructing schedules by hand and by the UNIFORM program are supposed to be the same, and the inability of user personnel to distinguish between schedules created by the two methods, the improvement in leveling of the daily manhour requirements for all trade skills and for the production shops was unexpected. The hypothesis for this result, unsupported by evidence, is that even though the schedule creation rules are the same, the

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Table 4.1

TABLE OF t-SCORES FOR COMPARISON OF
UNIFORM VERSUS HAND-CREATED SCHEDULES

	Statistics Compared Pairwise			
	Not Normalized		Normalized	
Entities Compared	Std Dev	Max-Min	Mean Dev	Dif/Mean
Critical Trade Skills n = 40	0.596	1.166	0.042	1.509
All Trade Skills n = 256	1.528	2.902	1.694	0.966
All Production Shops n = 557	1.529	2.466	4.544	2.085

Notes 1. Underlined scores indicated statistics which are significantly improved by the UNIFORM schedule.

2. Trade skills and production shops with a mean daily requirement of 1.0 hour or less have been omitted from tests.

computer is more strict in their application. The logical extension of this line of thought is that the rules have a sound basis for their existence; i.e. years of experience have provided a sound method for hand-creation of schedules, but human failings degradate their results.

4.5.2.2 Comparison of Schedules Created by Various ONEWAY Alternative Schedule Selection Criteria

Four of the ten different alternate schedule selection criteria listed at the end of the last chapter have been tested by creation of the quarterly schedules for the entire two year period. One of those four involved weighting based upon the critical trade skill priority; the other three did not involve weighting.

4.5.2.2.1 ONEWAY Interchanges Using Weighted Mean Deviations

The first ONEWAY schedule selection criterion tested was choice number ten, maximize the sum of average/standard deviation ratios (mean deviations) for the critical trade skills, weighting the mean deviations by a value equal to ten minus the trade skill priority. The large t-Score value achieved by the UNIFORM versus hand-created schedules, when compared by their mean deviations, was the basis for choosing the mean deviation selection alternative for the first testing of ONEWAY. (In Table 4.1 the values for mean deviations for all trade skills and all production shops are 1.691 and 4.544 respectively.)

The first testing of ONEWAY, for weighted mean deviations, produced outstanding results with respect to the levelling of the daily manhour requirements for the critical trade skills, both with respect to the hand-created and the UNIFORM schedules. The results for

Table 4.2

TABLE OF t-SCORES FOR COMPARISON OF SCHEDULES CREATED BY HAND AND BY THE UNIFORM AND ONEWAY PROGRAMS

	Statistics Compared Pairwise			
	Not Normalized		Normalized	
Compared	Std Dev	Max-Min	Mean Dev	Dif/Mean
ONEWAY Weighted Mean Deviation Schedule Vs UNIFORM Schedule				
Critical Skills	4.356	3.327	5.728	3.706
All Skills	1.801	0.425	3.194	-1.882
All Shops	0.512	-1.810	-3.431	-4.648
ONEWAY Weighted Mean Deviation Schedule Vs Hand-Created Schedule				
Critical Skills	4.477	3.861	5.561	4.448
All Skills	3.180	2.782	4.392	-1.085
All Shops	1.044	0.742	1.843	-2.526
UNIFORM Schedules Vs Hand-Created Schedules	(Repeated from Table 4.1)			
Critical Skills	0.596	1.166	0.042	1.509
All Skills	1.523	2.902	1.694	0.966
All Shops	1.529	2.466	4.544	2.085

Notes

1. Underlined scores indicate schedule statistics which are significantly improved for the first named schedule over the second named schedule.

2. The number of pairwise comparisons in each test is greater than 39.

levelling with respect to all trade skills and all production shops were mixed. Table 4.2 contains the t-Scores for comparison of these three sets of quarterly schedules.

4.5.2.2.2 <u>ONEWAY Interchanges Using Unweighted Mean Deviations</u>

A study of the myriad data produced by the computer program that compares the various schedules gave rise to questioning of the validity for utilization of a set of weights for the critical trade skills during the selection of alternate schedules in the ONEWAY program. In particular, a hypothesis was generated that the poor showing in the levelling of all shops and all skills might be the result of excessive biasing by the weighted values of the two highest priority, critical skills toward the assembly and disassembly operations in the facility, and away from other operations that involve a greater proportion of the shops and trade skills. This led to the choice of unweighted mean deviations, the fifth alternative criterion for ONEWAY schedule selection, as the second method to be tested.

The results of the second testing of ONEWAY schedules did not go exactly as hypothesized. As shown in Table 4.3, three significant changes occurred with respect to the ONEWAY schedules created earlier by the weighted mean deviation alternative. Two positive improvements occurred with respect to the levelling of the mean deviations for the critical skills and for all of the skills, but there was a significant decrease in the levelling of the mean deviations for all of the production shops. When compared with the UNIFORM schedules, the new ONEWAY schedules, created by the unweighted mean deviation alternative, were slightly, but not significantly, better than the ONEWAY schedules created earlier by the weighted mean deviation alternative.

Table 4.3

TABLE OF t-SCORES FOR COMPARISON OF SCHEDULES CREATED BY UNIFORM AND ONEWAY PROGRAMS

	Statistics Compared Pairwise			
	Not Normalized		Normalized	
Entities Compared	Std Dev	Max-Min	Mean Dev	Dif/Mean
Critical Skills	0.511	0.988	2.070	1.858
All Skills	0.679	-0.132	2.177	-0.382
All Shops	-1.528	0.023	-2.434	0.639
ONEWAY Unweighted Mean Deviation Schedule Vs UNIFORM Schedule				
Critical Skills	4.296	3.885	6.324	5.477
All Skills	1.907	0.302	4.124	-1.644
All Shops	0.271	-1.674	-2.314	-4.252
ONEWAY Weighted Mean Deviation Schedule Vs UNIFORM Schedule		(Repeated from Table 4.2)		
Critical Skills	4.356	3.327	5.728	3.706
All Skills	1.801	0.425	3.194	-1.882
All Shops	-0.512	-1.810	-3.431	-4.648

Note 1. Underlined scores indicate first schedule named is significantly better than the second schedule named.

2. The number of pairwise comparisons in each test is greater than 39.

4.5.2.2.3 ONEWAY Interchanges Using Unweighted Minimum Divided by Maximum Ratios of Daily Requirements

The next type of ONEWAY alternative schedule selection criterion to be tested was the one utilizing the minimum divided by maximum daily manhour requirement ratios. The result was an improvement in the levelling of all trade skill's and all production shops' manhour requirements, but at the expense of a degradation of the levelling of the daily requirements for the critical trade skills. Table 4.4 compares the results for the three different types of ONEWAY schedule selection alternatives tested to this point.

4.5.2.2.4 ONEWAY Interchanges Using the Minimum Sum of Unweighted Standard Deviations

The last type of ONEWAY alternative schedule selection tested was the fourth alternative among the unweighted ones, namely the minimization of the sum of unweighted standard deviations for the five critical trade skills. Compared to the previous creation methods evaluated, this choice of methods ranked very low by all statistical measures; so low in fact that the comparative results have not been included herein.

4.6 Overtime Hours as a Measure of Effectiveness

While the use of t-Scores as a measure of effectiveness is academically sound, it does not provide a measure that is readily understandable to the typical user of an interactive scheduling system. As mentioned earlier, the user is interested in a measure which somehow may be easily related to the "bottom line"; how does it affect

Table 4.4

TABLE OF t-SCORES FOR COMPARISON OF SCHEDULES CREATED BY ONEWAY PROGRAM ALTERNATIVES

	Statistics Compared Pairwise			
	Not Normalized		Normalized	
Entities Compared	Std Dev	Max-Min	Mean Dev	Dif/Mean
ONEWAY Unweighted Min/Max Ratio Schedules Versus ONEWAY Unweighted Mean Deviation Schedule				
Critical Skills	-2.507	-1.252	-4.663	-1.492
All Skills	-0.814	0.864	-1.949	2.059
All Shops	-0.937	0.500	1.823	2.819
ONEWAY Unweighted Min/Max Ration Schedules Versus ONEWAY Weighted Mean Deviation Schedule				
Critical Skills	-2.347	-0.577	-3.681	0.048
All Skills	-0.423	0.906	-0.714	2.161
All Shops	0.171	0.561	3.227	2.616
ONEWAY Unweighted Mean Deviation Schedules Vs ONEWAY Weighted Mean Deviation Schedules	(Repeated from Table 4.3)			
Critical Skills	0.511	0.988	2.070	1.858
All Skills	0.679	-0.132	2.177	-0.382
All Shops	-1.528	0.023	-2.434	0.639

Notes

1. Underlined scores indicate first schedule named is significantly better than the second schedule named.
2. The number of pairwise comparisons in each test is greater than 39.

the profit or loss for the firm. Any measure that provides such a relationship must contain dollars as a unit, or else be one that may be easily coverted to dollars.

In the original statement of the problem by the user(s), concern was expressed over the excess number of manhours that were being generated by the then-current work loads for certain trade skills. This interest in reduction of overtime eventually gave rise to the following measure of effectiveness applied for the user's sake.

The first step in the calculation of overtime hours, that arise from any given induction schedule, is the development of a sound basis for determining the value for each trade skill beyond which any daily manhour requirement for that trade skill leads to overtime. At first glance one might assume that the current number of employees in each trade skill could be used to calculate the regular-time versus overtime cutoff-point for each trade skill. Such a method may often be rejected out-of-hand, on the basis of the fact that some of the skills may well be inordinately over or under-manned at the current point in time for a various number of reasons. In this instance the current-number-of employee basis has to be rejected because the aircraft overhaul workload is only one of the components making up the entire workload for all employees of the facility. Therefore, a pseudo-current manpower level had to be developed for use as a basis in determining the regular-overtime cutoff-point, and this pseudo level has to be one that is considered as acceptable by the user.

Given a schedule for the two years, created by any of the methods described earlier, one can easily determine the average daily workload for each of the individual trade skills which must be available in order

to complete the number of products required over the two years. The user has agreed that this figure is acceptable as a fixed regular-time, manhour availability for each trade skill.

With such a fixed value for each trade skill in hand, the problem of overtime calculation for a schedule created by a given method is simply one of summing the two years excess daily manhours over the cutoff value for each trade skill, and then combining the accumulations for each of the trade skills into sums representing the critical trade skills for one measure, and for all trade skills as another.

These critical and all trade skill sums were calculated for all five schedules compared earlier by the paired difference t-scores. Table 4.5 shows the summations and the rankings for all five schedules. Of interest is the fact that the rankings of the schedules would be the same for both the critical and all skills values, and the fact that the rankings correspond very well with a ranking developed as a result of the earlier t-Score testing.

When shown the results comparing the hand-created schedule with the ONEWAY, weighted mean deviation schedule the users voiced a slight objection to simple comparison of the raw daily predictions, claiming that some smoothing of the workloads occurs as a result of shop supervisor actions on a daily basis. After some discussion between developer and user, it was agreed that the most discretion that could be exercised by the supervisors was to move a portion of their workload up to one day either way. Any further shifting of workload by an individual supervisor is impractical because of the impact it would have on earlier, or subsequent, operations within the current phase, or on subsequent phases. Any longer-duration, coordinated shifting by a

Table 4.5

OVERTIME HOURS REQUIRED
BY EACH OF THE
SCHEDULES CREATED BY DIFFERENT METHODS

		TRADE SKILLS	
RANKING	METHOD	ALL	CRITICAL
1	ONEWAY, WEIGHTED MEAN DEVIATIONS	107,259	50,548
2	ONEWAY, UNWEIGHTED MEAN DEVIATIONS	107,963	51,359
3	ONEWAY, UNWEIGHTED MIN/MAX RATIOS	109,894	54,382
4	UNIFORM	112,551	60,469
5	HAND-CREATED	116,305	62,390

Agreement on the "one day, either way" shifting capability allowed application of a three-day running average as a smoothing function for the predicted daily manhour requirements associated with any of the schedules created. After smoothing in such a fashion, the data can then be reevaluated to calculate the two-year overtime requirements for both the critical skills and for all of the trade skills.

Table 4.5 shows that the ONEWAY schedule creation alternative involving the weighted mean deviations ranked highest in savings when the raw (unsmoothed) schedule data were compared against the hand-created schedule data. Table 4.6 shows the resulting savings of this ONEWAY schedule over the hand-created schedule.

The ratio of smoothed to unsmoothed overtime hours is approximately .85 for all four cases (two different schedules, and two skill measures). The range of these four ratios is very narrow, .838 to .862, and the average of the four is .8505. Hence, one can say that, for this system, the reduction in overtime from the raw data predictions to the smoothed data predictions will be about fifteen percent.

Also of interest in this comparison is the relation of overtime hours saved to dollars saved. Table 4.7 contains an extract from a current (as of April 1, 1980) pay table for employees of this facility. The vast majority of the production workers in this facility fall into wage grades 8 through 10, and there are five time-in-grade steps for each grade. The average hourly wage for the thirty levels and grades in this extract is $9.42. When multiplied by a time-and-one-half overtime figure, this works out to a cost of $14.13 per average hour of overtime. Reduction in the all skills overtime represented by the best

Table 4.6

COMPARISON OF SCHEDULES
BASED UPON OVERTIME HOURS REQUIRED
(Smoothed Predictions)

	OVERTIME HOURS REQUIRED		
	HAND-CREATED SCHEDULE	ONEWAY SCHEDULE	NET SAVINGS
PREDICTED REQUIREMENTS (RAW)			
ALL SKILLS	116,305	107,259	9,049
CRITICAL SKILLS	62,390	50,548	11,842
PREDICTED REQUIREMENTS (SMOOTHED)			
ALL SKILLS	98,168	89,909	8,259
CRITICAL SKILLS	53,539	43,548	9,955

Table 4.7

HOURLY WAGE RATES FOR PRODUCTION EMPLOYEES

WG RATES

GRADES	1	2	3	4	5
8	7.72	8.04	8.36	8.68	9.00
9	8.28	8.63	8.98	9.32	9.67
10	8.84	9.21	9.58	9.95	10.32

WL RATES

GRADES	1	2	3	4	5
8	8.49	8.84	9.19	9.55	9.90
9	9.10	9.48	9.86	10.24	10.62
10	9.72	10.13	10.54	10.94	11.35

of the ONEWAY schedules versus the hand-created schedule is estimated at 8,259. Multiplying this hours figure by the $14.13 per hour cost would indicate a pseudo-savings of approximately $117,000 over the two-year period under consideration.

4.7 Execution Times for the ONEWAY Program

Before concluding this chapter on testing and analysis, there may be some value in looking at the differences in the computer execution times between the various alternatives of the ONEWAY program. Table 4.8 contains statistical data on the four different alternatives tested. Table 4.9 contains statistical data on pairwise comparison of three of these four alternatives.

Certain results from these two tables are worth noting at this point. First, consider the long durations for the maximum length runs of alternatives four and five. The average execution times for these two alternatives are both approximately thirty minutes, 33:45.9 and 28:56.8 respectively, but both required more than one hour of CPU time during the longest runs experienced. Alternative four did not achieve viable results in the levelling manhours objective so it can be discounted. Alternative five levelling results compared favorably with the results of alternative ten.

Second, these runs were made on a time-sharing system which, at the time, was not being utilized by any other user. This means that the computer's executive system overhead requirements for CPU time was at a minimum. Therefore the actual time from the start of execution to the termination of execution was also at a minimum.

Table 4.8

EXECUTION TIMES FOR THE
VARIOUS ONEWAY ALTERNATIVES

ONEWAY ALTERNATIVE	CPU EXECUTION TIMES (MIN:SECS) AVERAGE	STD DEV	MINIMUM	MAXIMUM
UNWEIGHTED				
3, MIN/MAX RATIO	5:06.8	6:43.3	1:35.4	13:54.7
4, STANDARD DEV	33:54.9	27:52.2	12:24.4	82:54.3
5, MEAN DEVIATION	28:56.8	20:14.8	9:03.6	71:14.5
WEIGHTED				
10,MEAN DEVIATION	23,17.8	9:01.5	8:45.9	34:42.2

Table 4.9

STATISTICAL COMPARISON OF THE
EXECUTION TIMES FOR THE VIABLE
ONEWAY ALTERNATIVES

ALTERNATIVES COMPARED	PAIRWISE DIFFERENCES FOR QUARTERS			
	AVERAGE DIF	STANDARD DEVIATION	t-SCORE	CONCLUSION
3 VERSUS 5	26:19.7	22:57.3	3.24	3 < 5
3 VERSUS 10	18:16.7	7:20.3	7.01	3 < 10
5 VERSUS 10	5:38.9	13:52.8	-1.15	NOT SIGNIF

Should the ONEWAY program be executed during the normal daytime user periods, one would have to expect execution duration times (not CPU times) to be far too excessive. It was this result that precluded another program segment, or an addition to ONEWAY, which would have allowed two-way interchanges in an attempt to gain further improvement of the schedules.

Third, although the fifth and tenth alternatives did not show themselves to be statistically different in execution time when compared by a pairwise difference test, intuitively one would consider the difference in the range of execution times for these two alternative to be significant. For example, the ranges shown by the minimum and maximum values of Table 4.8 are 9:04 to 71:15 and 8:46 to 34:52 respectively. For this reason alone one is inclined to lean rather heavily toward the use of the tenth alternative instead of the fifth, a conclusion supported in part by the difference in predicted overtime hours shown in Table 4.5

The reader may wonder whether or not the execution times for the oneway interchange search might not be reduced by application of an early stopping criterion. For example, one might stop the search for better schedules when the improvement from one schedule to the next is less than some small epsilon value. Figure 4.4 is a graphic example of the reason this concept will not work. This histogram shows the improvement of the objective value called devsum during a search. Note that there are numerous points where the histogram is level for a number of consecutive improvements, indicating that there is very little change from schedule to schedule. Had some early stopping criterion

been applied, the search might have stopped at one of these points, thereby foregoing the large improvements that occurred near the end of the search.

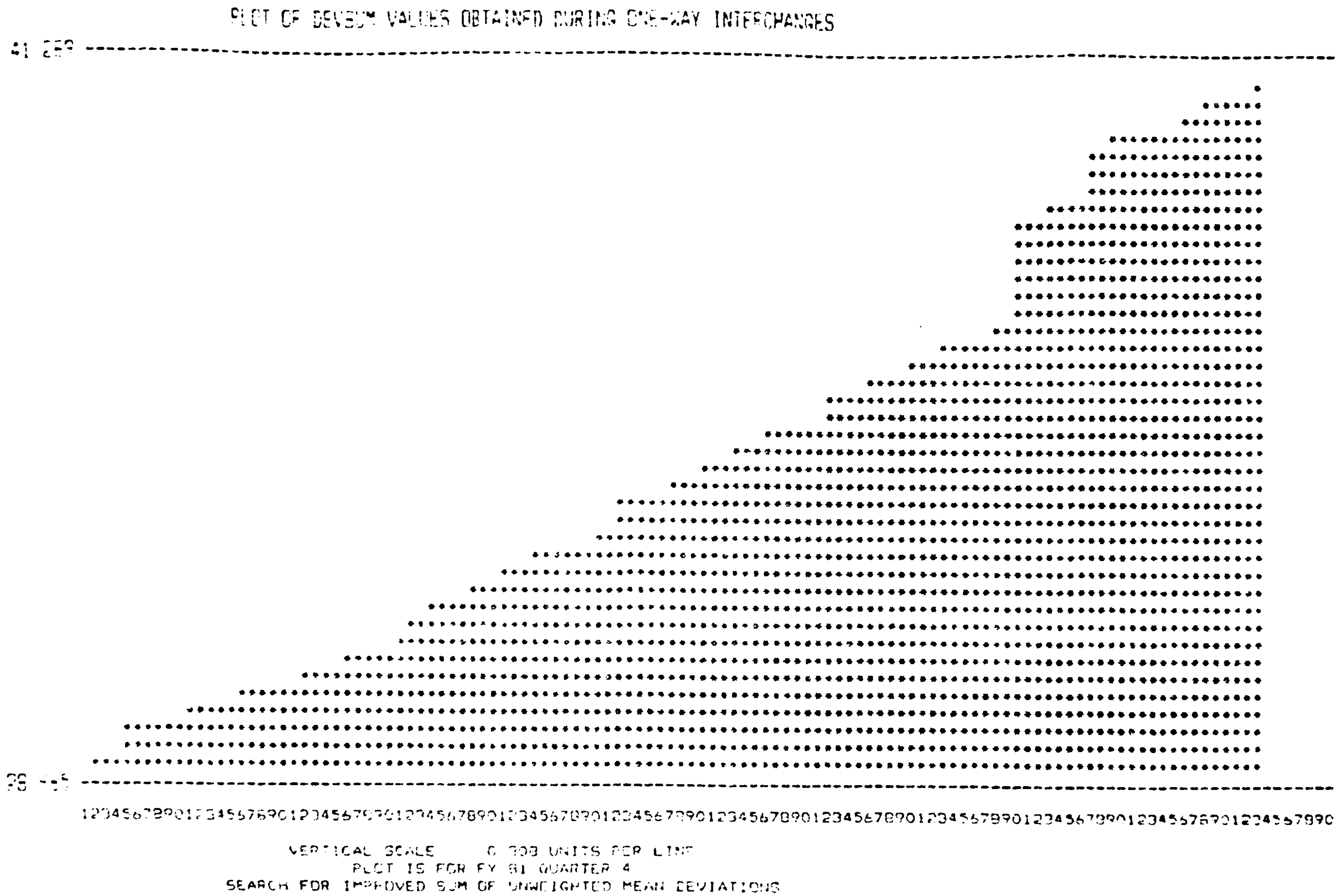


Figure 4.4 Histogram of Improving Objective Value During ONEWAY Search

CHAPTER 5

SUMMARY OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS FOR FURTHER STUDY

5.1 Restatement of the Research Objectives

At this point the reader may be feeling that this research effort has paralleled the voyage of Columbus in that, like Columbus, the developer started out not knowing where he was going, enroute did not know where he had been, on arriving did not know where he was, and did it all on government money. Therefore, before beginning a summary of the results it might be meaningful to clearly restate the objectives, so that the results can be stated within the framework of those objectives.

The study was meant to be applicatory in nature and, as such, it has attempted to investigate some rather narrow-based questions. Initially the goal of the research and development was primarily one of creating an interactive, production scheduling system for a completely generalized flowshop. This system was to reduce the swings in the daily manhour requirements for certain critical trade skills. The early phases of that development led to the conclusion that the methods normally utilized in such an effort would lead to failure. Specifically, it was assumed that any attempt to set fixed specifications for the system at an early point in its development would doom that system to a quick demise. This factor broadened the goal of the research to one of also creating a method for system development which would greatly improve the chances that that system would be successful as an

application. In the end, any application system being developed is ultimately judged as a success or failure by the potential user and not by the developer, the measure of success being whether or not the final product is adopted for future use within the facility for whom it was developed.

The two-way feedback loop came into use as a development tool very early in this project. Since neither the developer nor the user was constrained by any set of specifications, both were free to consider and to develop ideas for inclusion in the system that could not have been envisioned at the starting point.

A number of other aspects of development were conceived during the initial phase. For example, the decision was made at the outset to make use of whatever computer system capabilities were then available, thereby precluding future requirements for more sophisticated graphic displays or inputs. A second example is that of the limited number of assumptions built into the system. In fact, only one major assumption is included, that assumption being that the manhours required from a certain production shop during a particular phase on a given aircraft are assumed to be uniformly distributed over the shifts worked in completing that phase. This assumption had been in use for years within the scheduling division of the facility. A third example is the system's flexibility to changes in the data base underlying it; for example, the manhour standards change on a quarterly basis. A fourth, and very important facet, was the requirement for a complete management information system to precede the creation of a production scheduling system.

After these facets and others had been conceived and developed to their initial point, the article by Godin [3] was published. The hypotheses therein on the reasons for failure of other interactive systems lent structure and new impetus to the efforts to ensure success of this development. From that point on every step in the development was subjected to analysis based upon the failure hypotheses, and modified if necessary to overcome any shortcomings. In a sense, the goal for the study was broadened to include overcoming the common reasons for failure.

5.2 Summary of the Results

Given the broad goal of creating a successful interactive, production scheduling system, and thereby developing a method for such a creation, let us now look at the results.

5.2.1 Management Information System Results

The management information system was developed first, initially based upon only nineteen trade skills and then broadened to include up to sixty skills, with more than one skill assigned to a production shop. The system has undergone a tremendous number of changes since its inception, the complete list being only hinted at by the contents of the chronology of developments contained in Table 3.1. The MIS still contains the uniform distribution of manhours as the only underlying assumption. Its flexibility to change is demonstrated by the fact that the standard products have been changed, the organization of production shops has changed, the trade skills assigned to shops have changed, and the manhour standards have changed on a quarterly

basis. Sophistication of the MIS is demonstrated by the fact that the list of options for the PSKILL program contained in section 3.2.4.2.1 is only a partial statement of the entire range of system capabilities.

Results for the MIS from the user's point of view are outstanding. The system is utilized on a daily basis within the facility for which it was developed and, at the time of this writing, is being installed at a second, navy, overhaul facility, located at Pensacola, Florida. The implications of adverse product mixes for future periods are currently being analyzed and are providing a sound basis for the overcoming of bugetary and manpower level problems. Near future enhancements are currently being developed by the user for expanding the capabilities of the system to perform many of the other routine tasks within the production planning department. Probably the best indicator of the success of this portion of the system is that the developer receives after hours phone calls from the user, requesting for priority action on developing enhancements for which the user has created an urgent need; enhancements that provide data never before available but which are now almost mandatory in the performance of the production planning role.

As an aside, preliminary actions are now underway to begin the development of a more sophisticated system from the ground up. The new system, if developed, is to contain a further expansion of capabilities and features and, more importantly, it is to be compatible with, and adopted by, all six of the navy's aircraft overhaul facilities as a standard production MIS.

5.2.2 Scheduling System Results

Once the prototype for the MIS was completed, the development of the production scheduling system could begin. The delay in starting the scheduling portion of the system precluded its full evaluation by the user prior to the time of this writing. Therefore, the judgments of the user are not yet in, and any evaluation of the results must be limited to an analysis of the data presented in the last chapter. From that viewpoint, a summary of the results can be stated simply. Computer-created programs have been deemed as acceptable by the user with certainty at the UNIFORM program level, and with a high probability at the ONEWAY program level. The improvement in the levelling of daily manhour requirements for certain critical trade skills is attested to by both the high t-Scores attained in the paired difference tests and the manhour savings calculated in the overtime tests. In particular, one should refer to the t-Scores for all-skills and the critical skills contained in center portion of Table 4.2. There one sees the results for the Weighted Mean Deviation schedule of ONEWAY versus the hand-created schedule; with the paired difference t-Scores for critical skills all greater than 3.8. The overtime comparisons for the same two schedules are in Table 4.6. They show a reduction of critical skill overtime of almost 10,000 hours over the two years.

5.3 Conclusions and Recommendations for Further Research

Before stating the conclusions at which the developer arrived during this research it might be advisable to warn anyone who would attempt to apply this type of two-way feedback environment to the solution of an application problem in the future. This warning deals

with the background of the individual so embarking. In order to achieve the type of communications feedback and the rapidity of turn-around described earlier the developer must have the following:

(a) A very strong background in computer programming, beyond that which would normally be possessed by a graduate student with an undergraduate degree in computer science, and

(b) Some degree of experience in dealing with workers in an industrial management setting, either through experience working in that field, or preferrably a consulting background.

In other words, the development of an application of this type is not recommended for the typical doctoral student who has spent the entire portion of his or her adult life in a student environment. With that admonition it is now time to turn to the conclusions.

The first and most important conclusion of the developer at this point of the research is that the two-way feedback method of system development is both a necessity and practical. It is certain that the reader is asking himself "How does one ever reach a completion point in the development of an interactive system by such a method?" The answer to that question must necessarily be: "A truly useful system should be dynamic enough to reflect the changes in the environment in which it is to be utilized; therefore, it may never be completely developed in the true sense of the word completed." On the other hand, there must be some limit set for the developer to use as a guideline for the ultimate objective of his efforts, and there is always the problem of contractural agreement for payment purposes. This problem may well be an area for future research by a developer and a lawyer working jointly. At any rate, the author in this instance has no ready answer other than the possibility that the work be done under an open, cost-plus contract.

The second conclusion is that the swing in the requirements per unit of time for critical resources may be reduced without an excessive degradation in the requirements for other less critical resources, albeit not to the extent that the author hoped for in this instance. This area is wide open for future research.

The third conclusion is that there needs to be a great amount of research done in the area of scheduling completely generalized flowshops, and less done on the fictious three-job, three-machine type of problems with which many researchers have been content to concern themselves in the past. In particular, there is a need to expand the problem to one whereby the items currently in production are included when one is considering the solution of a scheduling problem for a set of unstarted tasks; i.e. the ongoing flowshop of real life situations.

Future research is also needed on the objective functions for generalized flowshops, particularly with respect to reducing the dispersion in the requirements per unit of time for the resources needed to complete a given production schedule. The high costs associated with idle-time for workers and the carrying of inventory are ones that are faced on a daily basis by managers and they are reflected in current reports of reduction in productivity rates by industrial nations.

APPENDIX A

SELECTED EXTRACTS FROM DATA FILES

INDUCTION VALUE LIMITS PER DAY 5.0
MAXIMUM NUMBER OF INDUCTIONS PER DAY 2.0
SCHEDULE LENGTH IS 520.0 DAYS
NUMBER OF TMS GROUPINGS IN THE SYSTEM IS 5.0 (MAXIMUM ALLOWED IS 18.0)

(GROUP NAME HAS MAXIMUM OF 8 CHARACTERS)

MAC #	NAME OF MACRO GROUP	NUMBER OF MEMBERS IN GROUP	SYMBOL	TMS MEMBERS OF GROUP
1.	A-7/MT	5.0	M	A-7A/MT A-7B/MT A-7C/MT A-7E/MT TA-7C/MT
2	A-7/SDLM	4.0	D	A-7A/SDM A-7B/SDM A-7C/SDM A-7E/SDM
3.	P-3/DLM	3.0	P	P-3A/DLM P-3B/DLM P-3C/DLM
4.	C-1&S-2	4.0	S	C-1A/SDM S-2D/SDM S-2E/SDM ES-2D/SD
5	S-2/FORN	1.0	F	S-2/FORN

NUMBER OF TMS DESCRIPTIONS IN SYSTEM IS 17.0 (MAXIMUM ALLOWED IS 32.0)

TMS #	TMS NAME	LENGTH DAYS	MACRO	DAVALU	SPREAD	SPVALU	SCHEDULE SEQUENCE
1	A-7A/MT	21.0	1.0	2.0	0.0	0.0	17.0
2	A-7B/MT	21.0	1.0	2.0	0.0	0.0	14.0
3	A-7C/MT	21.0	1.0	2.0	0.0	0.0	15.0
4	A-7E/MT	21.0	1.0	2.0	0.0	0.0	16.0
5	TA-7C/MT	21.0	1.0	2.0	0.0	0.0	13.0
6	A-7A/SDM	31.0	2.0	4.0	0.0	0.0	8.0
7	A-7B/SDM	31.0	2.0	4.0	0.0	0.0	5.0
8	A-7C/SDM	31.0	2.0	4.0	0.0	0.0	6.0
9.	A-7E/SDM	31.0	2.0	4.0	0.0	0.0	7.0
10	P-3A/DLM	52.0	3.0	5.0	3.0	1.0	3.0
11	P-3B/DLM	52.0	3.0	5.0	3.0	1.0	1.0
12	P-3C/DLM	52.0	3.0	5.0	3.0	1.0	2.0
13	C-1A/DLM	35.0	4.0	4.0	0.0	0.0	9.0
14	S-2D/DLM	35.0	4.0	4.0	0.0	0.0	12.0
15	S-2E/DLM	35.0	4.0	4.0	0.0	0.0	10.0
16	ES-2D/DL	35.0	4.0	4.0	0.0	0.0	11.0
17	S-2/FORN	60.0	5.0	4.0	0.0	0.0	4.0

NUMBER OF OPERATION NAMES IN THE SYSTEM IS 17.0 (MAXIMUM ALLOWED IS 24.0)

#	OPERATION NAME (MAXIMUM OF 16 CHARACTERS PER NAME)
1.	DEARM
2	E AND E
3.	PRESERVE/AERATE
4.	DISASSEMBLY
5.	COMPONENT REWORK
6.	STRIP/CORR TREAT
7	POST/STRP DISASY
8	PRIME/SEAL ACFT
9	ASSEMBLY (METAL)
10	ASSEMBLY (OTHER)
11	CLEAN AND PAINT
12	WEIGHT & BALANCE
13	GRND & FLT CHECK
14	RFI PAINT TUCHUP
15	RFI FINAL CHECK
16.	LOG ROOM
17.	SERVICE

AIRCRAFT Data File (Segment 1)

NUMBER OF TRADE SKILLS CURRENTLY IN SYSTEM 49.0 (MAXIMUM ALLOWED IS 60.0)

(SKILL ABBREVIATION HAS MAXIMUM OF 8 CHARACTERS)

SKILL NUMBER	SKILL ABBVN	SKILL NAME
1	A/C ELEC	AIRCRAFT ELECTRICIAN
2	A/C MECH	AIRCRAFT MECHANIC
3	BRNG REC	BEARING RECONDITIONER
4	ELEC EQP	ELECTRIC EQUIPMENT REPAIR
5	ELECTRCN	ELECTRICIAN
6	ELECPLTR	ELECTROPLATER
7	ELECTRON	ELECTRONICS MECHANIC
8	ENG MECH	ENGINE MECHANIC
9	EQP CLNR	EQUIPMENT CLEANER
10	EQP MECH	EQUIPMENT MARINE MECHANIC
11	FORKLIFT	FORKLIFT OPERATOR
12	GRAPHICS	GRAPHIC ARTS MECHANIC
13	GRND EQP	AIRCRAFT GROUND EQUIPMENT SPEC
14	HEAT TRT	HEAT TREATER
15	INSTRMNT	INSTRUMENT MECHANIC
16	MACHINST	MACHINIST
17	MACHNTOL	MACHINE TOOL OPERATOR
18	MLDPLAST	MOLDER PLASTICS
19	MOLDER	MOLDER
20	MTL INSP	METALS INSPECTOR
21	MTLIZING	METALIZING EQUIPMENT OPERATOR
22	ORDNANCE	ORDNANCE SYSTEMS
23	OXY MECH	AIRCRAFT OXYGEN EQUIPMENT MECH
24	PAINTER	PAINTER
25	PATRNMKR	PATTERN MAKER
26	PIPE FIT	PIPE FITTER
27	PLSTFIBR	PLASTICS AND FIBERGLASS
28	PNE MECH	PNE SYSTEMS MECHANIC
29	PRES PKG	PRESERVATION PACKAGER
30	PRES SVC	PRESERVATION SERVICER
31	PROPMECH	AIRCRAFT PROPELLER MECHANIC
32	PWRSUPRT	POWERED SUPPORT SYSTEMS MECHANIC
33	RIGGER	RIGGER
34	RUBBER	AIRCRAFT RUBBER MECHANIC
35	SHEETMTL	SHEET METAL MECHANIC
36	SHIP FIT	SHIP FITTER
37	SHOTPEEN	SHOT PEEN
38	SANDBLST	SANDBLASTER
39	SERVCTRD	SERVICE TRADES
40	TOOLGNDR	TOOL AND CUTTER GRINDER
41	TOOLMAKR	MACHINE TOOL MAKER
42	TRONMEAS	ELECTRONIC MEASURES MECHANIC
43	TRON SYS	ELECTRONIC SYSTEMS MECHANIC
44	UPHOLSTR	UPHOLSTERER
45	WELDER	WELDER
46	FOREMAN	FOREMAN
47	E AND E	ESTIMATOR AND EVALUATOR
48	P/C ELEC	PLANE CAPT A/C ELECTRICIAN
49	P/C MECH	PLANE CAPT A/C MECHANIC

AIRCRAFT Data File (Segment 2)

Trade Skill Sequence, Abbreviations, and Names

NUMBER OF PRODUCTION SHOPS IN SYSTEM 125 0 (MAXIMUM ALLOWED IS 120 0)

SHOP	# SKILLS	TRADESKILL	PERCENT	TRADESKILL	PERCENT	TRADESKILL	PERCENT	TRADESKILL	PERCENT	TRADESKILL	PERCENT	TRADESKILL	PERCENT	TRADESKILL	PERCENT	TRADESKILL	PERCENT	TRADESKILL	PERCENT	TRADESKILL	PERCENT
05	1	39	1 0																		
100	1	39	1.0																		
200	1	39	1 0																		
300	1	39	1 0																		
380	1	39	1 0																		
400	1	39	1 0																		
500	1	39	1.0																		
512	1	39	1.0																		
515	1	39	1.0																		
521	1	39	1.0																		
522	1	39	1.0																		
526	1	47	1 0																		
600	1	39	1 0																		
650	1	39	1 0																		
680	1	39	1 0																		
800	1	39	1 0																		
3111	1	9	1 0																		
3112	1	9	1 0																		
3113	3	6	57	9	21	38	22														
3115	1	24	1 0																		
3116	1	24	1 0																		
3151	1	30	1 0																		
3152	1	30	1 0																		
3154	1	29	1 0																		
3155	1	44	1 0																		
3156	1	34	1 0																		
3211	1	2	1 0																		
3212	1	2	1 0																		
3215	1	35	1 0																		
3216	1	22	1 0																		
3217	1	23	1 0																		
3219	1	23	1 0																		
3221	2	2	.14	28	.86																
3222	2	2	15	28	85																
3223	1	31	1 0																		
3224	1	2	1 0																		
3225	1	2	1 0																		
3226	1	3	1 0																		

AIRCRAFT Data File (Segment 3)

Allocation of Production Shop Manhours to Trade Skills
(Section 1)

```
3227  7  4  13  5  03 13  13 17  03 32  57 35 .06 45 .03
3228  6  5  08 10 .33 26  17 33  17 36  17 45 .08
3321  2 25  08 35 .92
3322  1 35 1 0
3323  2 35  25 45 .75
3324  1 14 1 0
3325  2 19 .67 35 .33
3327  2 18  20 27 .80
3331  1 35 1 0
3332  2  2  11 35 .89
3333  1 35 1 0
3334  1 35 1 0
3335  4  1 .09  2 .27 35 .55 45  07
3531  3  1  06 22 .86 35 .08
3532  1  1 1 0
3533  1  1 1.0
3534  1  1 1 0
4111  2  7  71 15 .29
4112  2  7  11 15 .89
4113  1 15 1 0
4114  2  7 .55 15 .45
4115  2  7  64 15 .36
4116  0  7 1 0
4117  2  7 .87 15 .13
4118  2  7  25 15 .75
4119  1 12 1 0
4121  2 15  83 24 .17
4241  1  7 1 0
4242  2  7  94 35  06
4243  1  7 1.0
4244  1  7 1.0
4461  1 42 1 0
4462  1 42 1 0
4463  1 42 1 0
4464  2 15  83 42  17
5111  2 27  06 35 .94
5112  2 27  06 35 .94
5141  1  2 1 0
5142  1  2 1 0
5143  1  2 1 0
5144  1  2 1 0
5171  1  1 1 0
5172  1  1 1 0
5175  2  7 .40 43 .60
5176  2  7  33 43  67
5221  2  2  23 35 .77
5222  3  1  57  2  14 35  29
5223  3  1  57  2  21 35  22
5245  5  1 .19  2  29 43  06 48  23 49  23
5246  5  1 .17  2  28 43  05 48  22 49  28
5611  2 27  05 35  95
5612  2 27  05 35 .95
5641  1  2 1 0
```

AIRCRAFT Data File (Segment 4)

Allocation of Production Shop Manhours to Trade Skills
(Section 2)

```
5642   1   2 1 0
5643   1   2 1 0
5644   1   2 1 0
5671   1   1 1 0
5672   1   1 1 0
5675   2   7  33 43  67
5676   2   7  33 43 .67
6101   1   8 1 0
6102   1   8 1 0
6103   1   8 1 0
6104   1   8 1 0
6105   1   8 1 0
6106   2 11 .17 30 .83
6107   1   8 1 0
6108   2   8  90 11 .10
6109   1   8 1 0
6223   3   9 .40 37 .33 38  27
6225 . 1   6 1. 0
6226   1 24 1 0
6227   1   6 1 0
6228   2   6  09 21 .91
6232   1 20 1 0
6233   1 20 1 0
6234   1 20 1 0
6235   1   8 1 0
6351   1 28 1 0
6352   1 28 1 0
6353   1 28 1 0
6356   2   9 .14 29  86
6411   2 16 .57 17 .43
6412   2 16  88 17 .12
6413   2 16  61 17 .39
6414   2 16  80 17 .20
6415   1 41 1 0


NUMBER OF OPERATION GROUPS CURRENTLY IN SYSTEM IS  7
OPERATION      OPERATION
  GROUP          GROUP
 NUMBER          NAME
---------    ---------------
     1        ESTIMAT & EVAL
     2        SVC,PRESV,AERATE
     3        A-7/S-2(DIS)ASSY
     4        P-3 (DIS)ASMBY
     5        COMPONENT REWORK
     6        CLEAN AND PAINT
     7.       GRND AND FLT CK
```

AIRCRAFT Data File (Segment 5)

Allocation of Production Shop Manhours to Trade Skills
(Section 3)

Definition of In-Process Operation Groupings

OPERATIONS IN WHICH THE SHOPS ARE INVOLVED

SHOP NUMBER	OPERATION NAME	OPN #	GROUP NUMBER
05	SERVICE	17	2
100	SERVICE	17	2
200	SERVICE	17	2
300	SERVICE	17	2
380	SERVICE	17	2
400	SERVICE	17	2
500	SERVICE	17	2
512	GRND & FLT CHECK	13	7
515	GRND & FLT CHECK	13	7
521	E AND E	2	1
522	E AND E	2	1
526	E AND E	2	1
600	E AND E	2	1
650	SERVICE	17	2
680	SERVICE	17	2
800	GRND & FLT CHECK	13	7
3111	COMPONENT REWORK	[illegible]	5
3112	STRIP/CORR TREAT	6	2
3113	COMPONENT REWORK	5	5
3115	COMPONENT REWORK	5	5
3116	CLEAN AND PAINT	11	6
3151	PRESERVE/AERATE	3	2
3152	PRESERVE/AERATE	3	2
3154	COMPONENT REWORK	5	5
3155	COMPONENT REWORK	5	5
3156	COMPONENT REWORK	5	5
3211	COMPONENT REWORK	5	5
3212	COMPONENT REWORK	5	5
3215	COMPONENT REWORK	5	5
3216	COMPONENT REWORK	5	5
3217	COMPONENT REWORK	5	5
3218	COMPONENT REWORK	5	5
3221	COMPONENT REWORK	5	5
3222	COMPONENT REWORK	5	5
3223	COMPONENT REWORK	5	5
3224	COMPONENT REWORK	5	5
3225	COMPONENT REWORK	5	5
3226	COMPONENT REWORK	5	5
3227	COMPONENT REWORK	5	5
3228	COMPONENT REWORK	5	5
3321	COMPONENT REWORK	5	5
3322	COMPONENT REWORK	5	5
3323	COMPONENT REWORK	5	5
3324	COMPONENT REWORK	5	5
3325	COMPONENT REWORK	5	5
3327	COMPONENT REWORK	5	5
3331	COMPONENT REWORK	5	5
3332	COMPONENT REWORK	5	5
3333	COMPONENT REWORK	5	5
3334	COMPONENT REWORK	5	5
3335	COMPONENT REWORK	5	5
3531	COMPONENT REWORK	5	5
3532	COMPONENT REWORK	5	5
3533	COMPONENT REWORK	5	5
3534	COMPONENT REWORK	5	5
4111	COMPONENT REWORK	5	5
4112	COMPONENT REWORK	5	5
4113	COMPONENT REWORK	5	5
4114	COMPONENT REWORK	5	5
4115	COMPONENT REWORK	5	5
4116	COMPONENT REWORK	5	[illegible]
4117	COMPONENT REWORK	5	5
4118	COMPONENT REWORK	5	5

AIRCRAFT Data File (Segment 6)

Assignment of In-Process Operations to Production Shops
(Section 1)

4119	COMPONENT REWORK	5	5
4121	COMPONENT REWORK	5	5
4241	COMPONENT REWORK	5	5
4242	COMPONENT REWORK	5	5
4243	COMPONENT REWORK	5	5
4244	COMPONENT REWORK	5	5
4461	NOT INVOLVED	0	0
4462	NOT INVOLVED	0	0
4463	NOT INVOLVED	0	0
4464	NOT INVOLVED	0	0
5111	ASSEMBLY (METAL)	9	3
5112	ASSEMBLY (METAL)	9	3
5141	ASSEMBLY (OTHER)	10	3
5142	ASSEMBLY (OTHER)	10	3
5143	ASSEMBLY (OTHER)	10	3
5144	ASSEMBLY (OTHER)	10	3
5171	ASSEMBLY (OTHER)	10	3
5172	ASSEMBLY (OTHER)	10	3
5175	ASSEMBLY (METAL)	9	3
5176	ASSEMBLY (METAL)	9	3
5221	ASSEMBLY (OTHER)	10	3
5222	ASSEMBLY (OTHER)	10	3
5223	ASSEMBLY (OTHER)	10	3
5245	GRND & FLT CHECK	13	7
5246	GRND FLT CHECK	13	7
5611	ASSEMBLY (METAL)	9	4
5612	ASSEMBLY (METAL)	9	4
5641	ASSEMBLY (OTHER)	10	4
5642	ASSEMBLY (OTHER)	10	4
5643	ASSEMBLY (OTHER)	10	4
5644	ASSEMBLY (OTHER)	10	4
5671	ASSEMBLY (OTHER)	10	4
5672	ASSEMBLY (OTHER)	10	4
5675	ASSEMBLY (METAL)	9	4
5176	ASSEMBLY (METAL)	9	4
6101	COMPONENT REWORK	5	5
6102	COMPONENT REWORK	5	5
6103	COMPONENT REWORK	5	5
6104	COMPONENT REWORK	5	5
6105	COMPONENT REWORK	5	5
6106	COMPONENT REWORK	5	5
6107	COMPONENT REWORK	5	5
6108	COMPONENT REWORK	5	5
6109	COMPONENT REWORK	5	5
6223	COMPONENT REWORK	5	5
6225	COMPONENT REWORK	5	5
6226	COMPONENT REWORK	5	5
6227	COMPONENT REWORK	5	5
6228	COMPONENT REWORK	5	5
6232	COMPONENT REWORK	5	5
6233	COMPONENT REWORK	5	5
6234	COMPONENT REWORK	5	5
6235	COMPONENT REWORK	5	5
6351	COMPONENT REWORK	5	5
6352	COMPONENT REWORK	5	5
6353	COMPONENT REWORK	5	5
6356	COMPONENT REWORK	5	5
6411	COMPONENT REWORK	5	5
6412	COMPONENT REWORK	5	5
6413	COMPONENT REWORK	5	5
6414	COMPONENT REWORK	5	5
6415	COMPONENT REWORK	5	5

THE NUMBER OF SHIFTS WORKED PER DAY IS 2.0

AIRCRAFT Data File (Segment 7)

Assignment of In-Process Operations to Production Shops
(Section 2)

NUMBER OF EQUIVALENT OPERATIONS FOR DISTRIBUTION OF SHOP MANHOURS 6 0 (MAXIMUM ALLOWED IS 12 0)

LISTED OPERATION: OPERATION NAME	NUMBER	EQUIVALENT OPERATION: OPERATION NAME	NUMBER
DISASSEMBLY	4 0	ASSEMBLY (OTHER)	10 0
POSTSTRIP DISASY	7 0	ASSEMBLY (OTHER)	10 0
PRIME/SEAL ACFT	8 0	CLEAN AND PAINT	11 0
RFI PAINT TUCHUP	14 0	CLEAN AND PAINT	11 0
RFI FINAL CHECK	15 0	GRND & FLT CHECK	13 0
LOG ROOM	16 0	E AND E	2 0

TMS GROUP NUMBER AND NAME 1 0 A-7/MT
NUMBER OF OPERATIONS IN TMS IN-PROCESS CYCLE 12 0

OPERATION NAME	OPERATION NUMBER	STARTING SHIFT	ENDING SHIFT
E AND E	2 0	1 0	1 0
PRESERVE/AERATE	3 0	1 0	1 0
DISASSEMBLY	4 0	2 0	2 0
COMPONENT REWORK	5 0	3 0	18 0
STRIP/CORR TREAT	6 0	3 0	9 0
PRIME SEAL A/C	8 0	10 0	11 0
POST STRIP DISASY	7 0	12 0	12 0
E AND E	2 0	13 0	13 0
ASSEMBLY (METAL)	9 0	14 0	[illegible]
ASSEMBLY (OTHER)	10 0	19 0	26 0
CLEAN AND PAINT	11 0	27 0	32 0
GRND & FLT CHECK	13 0	33 0	42 0

TMS GROUP NUMBER AND NAME 2 0 A-7/SDLM
NUMBER OF OPERATIONS IN TMS IN-PROCESS CYCLE 14 0

OPERATION NAME	OPERATION NUMBER	STARTING SHIFT	ENDING SHIFT
E AND E	2 0	1 0	1 0
PRESERVE/AERATE	3 0	1 0	1 0
DISASSEMBLY	4 0	2 0	2 0
COMPONENT REWORK	5 0	3 0	[illegible]
STRIP/CORR TREAT	6 0	3 0	9 0
PRIME/SEAL ACFT	8 0	10 0	11 0
POST/STRP DISASY	7 0	12 0	13 0
E AND E	2 0	14 0	[illegible]
ASSEMBLY (METAL)	9 0	16 0	[illegible]
ASSEMBLY (OTHER)	10 0	27 0	44 0
CLEAN AND PAINT	11 0	45 0	[illegible]
GRND & FLT CHECK	13 0	51 0	60 0
RFI PAINT TUCHUP	14 0	61 0	61 0
RFI FINAL CHECK	15 0	62 0	62 0

AIRCRAFT Data File (Segment 8)

Equivalent In-Process Operations

In-Process Sequence and Durations by MACRC Group
(Section 1)

TMS GROUP NUMBER AND NAME 3 0 P-3/DLM
NUMBER OF OPERATIONS IN TMS IN-PROCESS CYCLE 13 0

OPERATION NAME	OPERATION NUMBER	STARTING SHIFT	ENDING SHIFT
E AND E	2 0	1 0	3 0
PRESERVE/AERATE	3 0	3 0	7 0
STRIP/CORR TREAT	6 0	8 0	17 0
DISASSEMBLY	4 0	18 0	24 0
E AND E	2 0	25 0	28 0
COMPONENT REWORK	5 0	25 0	60 0
ASSEMBLY (METAL)	9 0	29 0	60 0
ASSEMBLY (OTHER)	10 0	51 0	78 0
CLEAN AND PAINT	11 0	79 0	86 0
GRND & FLT CHECK	13 0	87 0	100 0
WEIGHT AND BAL	12 0	87 0	100 0
RFI PAINT TUCHUP	14 0	101 0	103 0
RFI FINAL CHECK	15 0	104 0	104 0

TMS GROUP NUMBER AND NAME 4 0 C-1/2 2 DLM
NUMBER OF OPERATIONS IN TMS IN-PROCESS CYCLE 13 0

OPERATION NAME	OPERATION NUMBER	STARTING SHIFT	ENDING SHIFT
E AND E	2 0	1 0	2 0
PRESERVE/AERATE	3 0	3 0	4 0
DISASSEMBLY	4 0	5 0	5 0
COMPONENT REWORK	5 0	6 0	27 0
STRIP/CORR TREAT	6 0	[illegible]	11 0
POST/STRP DISASY	7 0	14 0	14 0
E AND E	2 0	15 0	17 0
ASSEMBLY (METAL)	9 0	18 0	27 0
ASSEMBLY (OTHER)	10 0	28 0	47 0
CLEAN AND PAINT	11 0	48 0	53 0
GRND & FLT CHECK	13 0	54 0	68 0
RFI PAINT TUCHUP	14 0	69 0	69 0
RFI FINAL CHECK	15 0	70 0	70 0

TMS GROUP NUMBER AND NAME 5 0 S-2 FOREIGN SALES
NUMBER OF OPERATIONS IN TMS IN-PROCESS CYCLE 13 0

OPERATION NAME	OPERATION NUMBER	STARTING SHIFT	ENDING SHIFT
E AND E	2 0	1 0	2 0
PRESERVE/AERATE	3 0	3 0	4 0
DISASSEMBLY	4 0	5 0	7 0
COMPONENT REWORK	5 0	8 0	35 0
STRIP/CORR TREAT	6 0	8 0	15 0
POST/STRP DISASY	7 0	16 0	18 0
E AND E	2 0	19 0	29 0
ASSEMBLY (METAL)	9 0	30 0	87 0
ASSEMBLY (OTHER)	10 0	30 0	87 0
CLEAN AND PAINT	11 0	90 0	97 0
GRND & FLT CHECK	13 0	98 0	118 0
RFI PAINT TUCHUP	14 0	119 0	119 0
RFI FINAL CHECK	15 0	120 0	120 0

AIRCRAFT Data File (Segment 9)

In-Process Sequence and Durations by MACRO Groups
(Section 2)

WORKLOAD STANDARDS EFFECTIVE 1ST QUARTER FY 1980

	1	2	3	4	5	6	7	8	TMS TYPES NEW TMS
HOP	A-7A/M	A-7B/M	A-7C/M	A-7E/M	TA-7C/M	A-7A/S	A-7B/S	A-7C/S	
03	0	0	0	0	0	0	0	0	
100	0	0	0	0	0	0	0	0	
200	0	0	0	0	0	0	0	0	
300	0	0	0	0	0	0	0	0	
380	0	0	0	0	0	0	0	0	
400	0	0	0	0	0	0	0	0	
500	0	0	0	0	0	0	0	0	
512	0	19	0	16	16	46	56	48	
515	0	0	0	0	0	8	8	8	
521	0	9	0	10	10	14	16	17	
522	0	0	0	0	0	13	18	13	
526	0	56	0	58	58	172	189	175	
600	0	0	0	0	0	0	4	4	
650	0	0	0	0	0	0	0	0	
680	0	0	0	0	0	0	0	0	
800	0	1	0	1	1	2	2	2	
SHOP	A-7A/M	A-7B/M	A-7C/M	A-7E/M	TA-7C/M	A-7A/S	A-7B/S	A-7C/S	
3111	0	10	0	26	26	51	109	55	
3112	0	198	0	198	198	206	202	199	
3113	0	2	0	6	6	15	37	12	
3115	0	8	0	7	7	17	40	36	
3116	0	228	0	228	228	182	192	181	
3151	0	12	0	8	8	14	14	14	
3152	0	0	0	0	0	0	0	0	
3154	0	0	0	0	0	0	0	0	
3155	0	0	0	1	1	4	9	9	
3156	0	0	0	4	4	10	16	7	
SHOP	A-7A/M	A-7B/M	A-7C/M	A-7E/M	TA-7C/M	A-7A/S	A-7B/S	A-7C/S	
3211	0	3	0	1	1	5	12	7	
3212	0	3	0	1	1	22	15	12	
3215	0	6	0	5	5	19	34	17	
3216	0	1	0	2	2	5	4	3	
3217	0	3	0	0	0	3	4	4	
3218	0	2	0	1	1	2	3	3	
3221	0	0	0	1	1	32	51	27	
3222	0	1	0	2	2	33	47	31	
3223	0	0	0	0	0	0	0	0	
3224	0	0	0	0	0	4	2	2	
3225	0	0	0	0	0	0	8	2	
3226	0	1	0	2	2	7	11	12	
3227	0	0	0	0	0	0	0	0	
3228	0	0	0	0	0	0	0	0	
SHOP	A-7A/M	A-7B/M	A-7C/M	A-7E/M	TA-7C/M	A-7A/S	A-7B/S	A-7C/S	
3321	0	0	0	0	0	4	2	2	
3322	0	0	0	1	1	7	11	7	
3323	0	0	0	0	0	5	15	11	
3324	0	0	0	0	0	0	1	2	
3325	0	0	0	0	0	0	0	1	
3327	0	1	0	0	0	12	33	18	
3331	0	0	0	0	0	21	[illegible]	[illegible]	
3332	0	0	0	0	0	6	63	17	
3333	0	0	0	0	0	8	4	21	
3334	0	0	0	0	0	0	0	0	
3335	0	1	0	0	0	10	4	12	
3531	0	20	0	16	16	31	26	16	
3532	0	3	0	2	2	10	12	15	
3533	0	0	0	1	1	6	23	18	
3534	0	0	0	0	0	6	0	7	

WORKLOAD Data File (Segment 1)

Allocation of Manhours to Production Shops by Aircraft Type

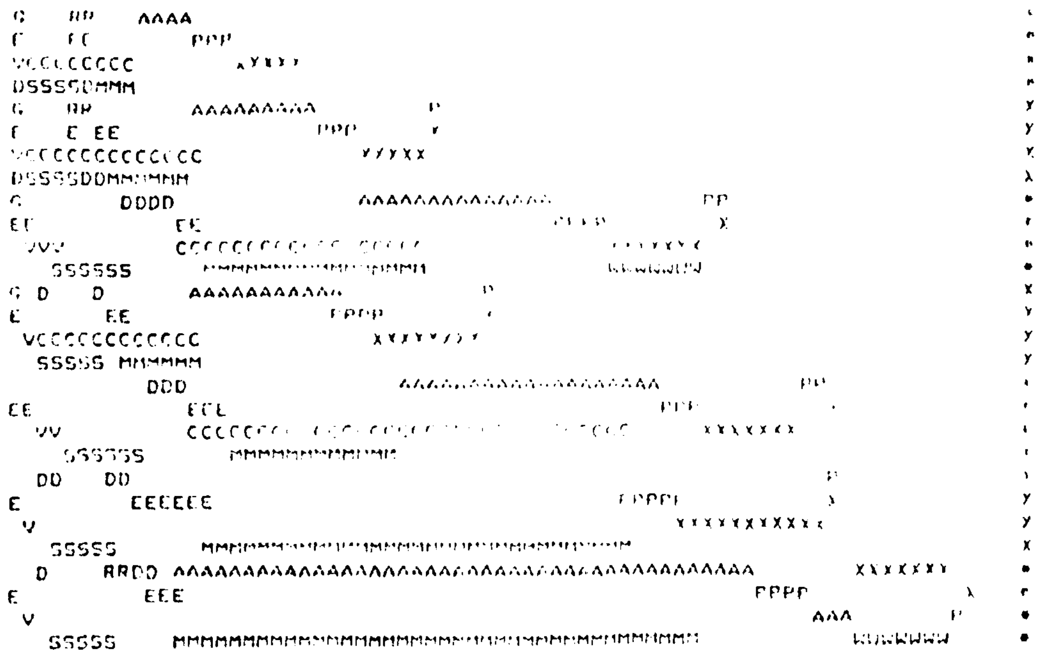
SHOP	A-7A/M	A-7B/M	A-7C/M	A-7E/M	TA-7C/M	A-7A/S	A-7B/S	A-7C/S
4111	0	9	0	0	0	0	25	5
4112	0	0	0	0	0	0	2	3
4113	0	1	0	1	1	[illegible]	4	3
4114	0	11	0	4	4	2	52	17
4115	0	4	0	5	5	23	36	7
4116	0	0	0	0	0	0	0	4
4117	0	0	0	0	0	0	2	0
4118	0	0	0	0	0	0	0	0
4119	0	0	0	0	0	0	0	2
4121	0	0	0	2	2	11	2	3
4241	0	3	0	0	0	12	5	3
4242	0	3	0	12	12	23	43	21
4243	0	0	0	1	1	9	1	3
4244	0	8	0	2	2	29	4	17
4261	0	0	0	0	0	0	0	0
4262	0	0	0	0	0	0	0	0
4263	0	0	0	0	0	0	0	0
4264	0	0	0	0	0	0	0	0

SHOP	A-7A/M	A-7B/M	A-7C/M	A-7E/M	TA-7C/M	A-7A/S	A-7B/S	A-7C/S
5111	0	113	0	113	113	440	573	239
5112	0	0	0	0	0	0	0	0
5141	0	55	0	124	124	235	475	596
5142	0	0	0	0	0	0	0	0
5143	0	126	0	111	111	654	341	621
5144	0	0	0	0	0	0	0	0
5171	0	29	0	30	30	164	275	245
5172	0	0	0	0	0	0	0	0
5175	0	13	0	17	17	94	139	126
5176	0	0	0	0	0	0	0	0
5221	0	0	0	0	0	0	0	0
5222	0	0	0	0	0	0	0	0
5223	0	0	0	0	0	0	0	0
5245	0	[illegible]	0	126	[illegible]	[illegible]	220	[illegible]
5246	0	0	0	0	0	0	0	0
5611	0	0	0	0	0	0	0	0
5612	0	0	0	0	0	0	0	0
5641	0	0	0	0	0	0	0	0
5642	0	0	0	0	0	0	0	0
5643	0	0	0	0	0	0	0	0
5644	0	0	0	0	0	0	0	0
5671	0	0	0	0	0	0	0	0
5672	0	0	0	0	0	0	0	0
5675	0	0	0	0	0	0	0	0
5676	0	0	0	0	0	0	0	0

WORKLOAD Data File (Segment 2)

SHOP	A-7A/M	A-7B/M	A-7C/M	A-7E/M	TA-7C/M	A-7A/S	A-7B/S	A-7C/S
6101	0	0	0	0	0	0	0	0
6102	0	0	0	0	0	0	0	0
6103	0	0	0	0	0	0	0	0
6104	0	2	0	1	1	60	39	32
6105	0	0	0	0	0	0	0	0
6106	0	0	0	0	0	0	0	0
6107	0	0	0	0	0	0	0	0
6108	0	0	0	0	0	0	1	0
6109	0	0	0	0	0	0	0	0
SHOP	A-7A/M	A-7B/M	A-7C/M	A-7E/M	TA-7C/M	A-7A/S	A-7B/S	A-7C/S
6223	0	0	0	0	0	2	4	1
6225	0	0	0	0	0	13	9	8
6226	0	0	0	0	0	1	1	1
6227	0	0	0	0	0	0	3	0
6228	0	0	0	0	0	0	0	0
6232	0	1	0	1	1	7	4	21
6233	0	0	0	0	0	1	12	2
6234	0	0	0	0	0	4	1	2
6235	0	0	0	0	0	0	0	0
SHOP	A-7A/M	A-7B/M	A-7C/M	A-7E/M	TA-7C/M	A-7A/S	A-7B/S	A-7C/S
6351	0	0	0	0	0	0	0	0
6352	0	0	0	0	0	[illegible]	4	4
6353	0	0	0	0	0	0	0	0
6354	0	0	0	0	0	0	0	0
6411	0	4	0	4	1	29	27	30
6412	0	0	0	0	0	3	0	14
6413	0	0	0	0	0	3	15	7
6414	0	0	0	0	0	2	0	1
6415	0	0	0	0	0	0	3	4

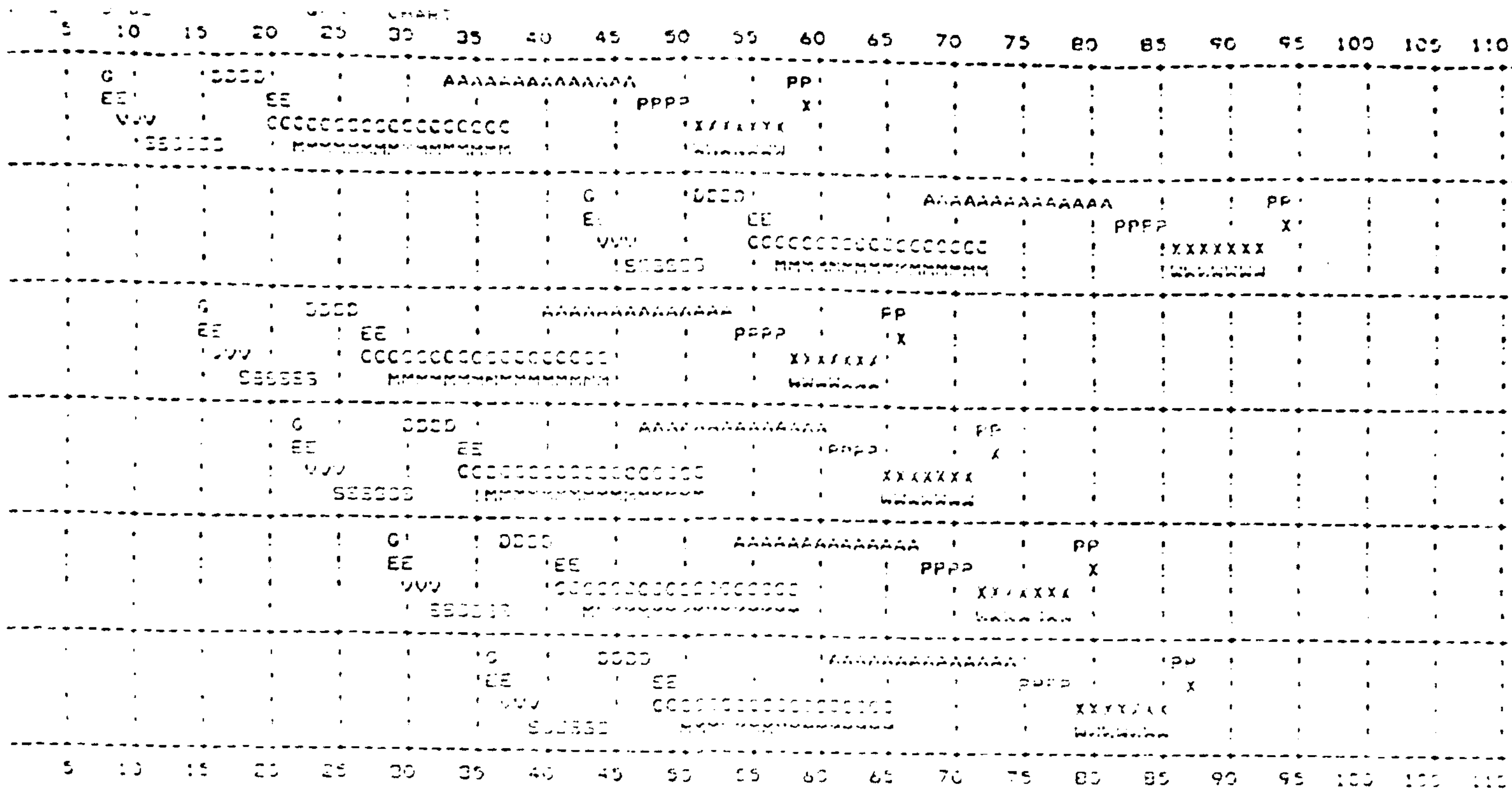
WORKLOAD Data File (Segment 3)



GANTT Data File Format

APPENDIX B

HARD-COPY PRINTOUT EXAMPLES



** SYMBOL DEFINITIONS **

G = DEARM	E = E AND E
V = PRESERVE/AERATE	D = DISASSEMBLY
C = COMPONENT REWORK	S = STRIP/CORR TREAT
D = POST/STRP DISASY	R = PRIME/SEAL ACFT
M = ASSEMBLY (METAL)	A = ASSEMBLY (OTHER)
P = CLEAN AND PAINT	W = WEIGHT & BALANCE
X = GRND & FLT CHECK	P = RFI PAINT TUCHUP
X = RFI FINAL CHECK	

GANTT Chart Created and Printed by the PSKILL Program

```
NO TYPE A-7A/MT              SCHEDULED THIS QUARTER
----------------------------------------------------------------------
*TYPE A-7B/MT              SCHEDULE
*             1    1   1   1           1        1  1  1        1    1
*     ------------------------------------------------------------------*
*          5    10   15   20   25   30   35   40   45   50   55
----------------------------------------------------------------------

NO TYPE A-7C/MT              SCHEDULED THIS QUARTER
----------------------------------------------------------------------
*TYPE A-7C/MT              SCHEDULE
*      1 11  1 1        1  1 1 1 1   1 1 1         1 2      1  1
*     ------------------------------------------------------------------*
*          5    10   15   20   25   30   35   40   45   50   55
----------------------------------------------------------------------

NO TYPE TA-7C/MT             SCHEDULED THIS QUARTER

NO TYPE A-7A/SDM             SCHEDULED THIS QUARTER
----------------------------------------------------------------------
*TYPE A-7B/SDM             SCHEDULE
*                  1
*     ------------------------------------------------------------------*
*          5    10   15   20   25   30   35   40   45   50   55
----------------------------------------------------------------------

NO TYPE A-7C/SDM             SCHEDULED THIS QUARTER
----------------------------------------------------------------------
*TYPE A-7E/SDM             SCHEDULE
*     1 1  1  1    1  1  1   1 1 1   1 1   1 1 1  1   1   1 1   1
*     ------------------------------------------------------------------*
*          5    10   15   20   25   30   35   40   45   50   55
----------------------------------------------------------------------

NO TYPE VP-3A                SCHEDULED THIS QUARTER
----------------------------------------------------------------------
*TYPE P-3B/DLM             SCHEDULE
*            1                                         1
*     ------------------------------------------------------------------*
*          5    10   15   20   25   30   35   40   45   50   55
----------------------------------------------------------------------
----------------------------------------------------------------------
*TYPE P-3C/DLM             SCHEDULE
*                    1       1      1       1
*     ------------------------------------------------------------------*
*          5    10   15   20   25   30   35   40   45   50   55
----------------------------------------------------------------------

NO TYPE C-1A/DLM             SCHEDULED THIS QUARTER

NO TYPE S-2D/DLM             SCHEDULED THIS QUARTER

NO TYPE S-2E/DLM             SCHEDULED THIS QUARTER
----------------------------------------------------------------------
*TYPE ES-2D/DL             SCHEDULE
*                                                          1
*     ------------------------------------------------------------------*
*          5    10   15   20   25   30   35   40   45   50   55
----------------------------------------------------------------------

NO TYPE S-2/FORN             SCHEDULED THIS QUARTER
----------------------------------------------------------------------
*TYPE RP-3A/149670 LG1 SCHEDULE
*    1
*     ------------------------------------------------------------------*
*          5    10   15   20   25   30   35   40   45   50   55
----------------------------------------------------------------------

NO TYPE P-3B/152754 LG2 SCHEDULED THIS QUARTER
----------------------------------------------------------------------
*TYPE P-3B/152754 LG2 SCHEDULE
*                    1
*     ------------------------------------------------------------------*
*          5    10   15   20   25   30   35   40   45   50   55
----------------------------------------------------------------------
```

Type-Order Schedule Displayed on CRT by PSKILL Program

REAL SCHEDULE FOR THE FIRST QUARTER OF FY 81 AS OF 08-APR-80

OCTOBER DAY	OCTOBER TYPE	NOVEMBER DAY	NOVEMBER TYPE	DECEMBER DAY	DECEMBER TYPE
001	P-3C/DLM	023	A-7E/SDM	040	
002	A7B/SDLM C/OSECI	024	A-7E/MT	041	A-7B/SDM
003	A-7B/SDM	025	TA-7C/MT	042	TA-7C/MT
004	A-7B/MT	026	A-7E/SDM	043	P-3C/DLM
	A-7E/MT	027	A-7E/MT	044	A-7E/SDM
005	TA-7C/MT	028	A-7E/SDM	045	
006	A-7E/SDM	029	P-3C/DLM	046	A-7E/MT
007	A-7E/MT	030	A-7B/MT	047	A-7E/SDM
008	VP-3A/DL		A-7E/MT		VP-3A/DL
009	A-7E/SDM	031	A-7E/SDM	048	TA-7C/MT
010	A-7E/MT	032	TA-7C/MT	049	A-7B/MT
011	A-7C/SDM	033	A-7E/MT	050	P-3B/DLM
012	A-7E/MT	034	A-7E/SDM	051	A-7E/SDM
013	TA-7C/MT	035	A-7B/MT	052	TA-7C/MT
014	A-7E/SDM	036	P-3B/DLM	053	A-7E/SDM
015	P-3C/DLM	037	A-7E/SDM		P-3C/DLM
016	A-7B/MT	038	A-7B/MT	054	TA-7C/MT
	A-7E/MT		A-7E/MT	055	A-7B/MT
017	A-7E/SDM	039	A-7E/SDM		A-7E/MT
018	A-7E/MT			056	A-7E/SDM
019	A-7E/MT			057	P-3C/DLM
020	A-7E/SDM				
021	A-7B/MT				
022	P-3B/DLM				

Day-Order Schedule Created and Printed by the PSKILL and ONEWAY Programs

UNIFORMLY DISTRIBUTED INITIAL SCHEDULE FOR 001 THRU 056
IN DAY ORDER

DAY	AIRCRAFT TYPE		DAY	AIRCRAFT TYPE
1	RF-3A/1439700[illegible]		29	A-7E/SDM
2	A-7E/SDM		30	A-7E/MT
3	A-7B/MT		31	A-7E/MT
3	A-7E/MT	(2)	32	A-7E/SDM
4	A-7E/SDM		33	P-3C/DLM
5	A-7E/MT		34	A-7E/MT
6	A-7E/MT		35	A-7E/SDM
7	P-3B/DLM		36	A-7E/MT
8	A-7E/MT		37	A-7E/SDM
9	P-3B/DLM		38	A-7B/MT
10	A-7E/SDM		39	A-7E/MT
11	A-7E/MT		40	A-7E/SDM
12	A-7E/SDM		41	A-7E/SDM
13	A-7E/MT		42	A-7B/MT
14	A-7E/MT		43	A-7E/SDM
15	A-7E/SDM		44	A-7E/MT
16	A-7E/SDM		45	A-7E/MT
17	P-3B/DLM		46	A-7E/SDM
18	A-7E/SDM		47	ES-[illegible]
19	A-7E/MT		48	A-7B/MT
20	A-7B/MT		49	P-3C/DLM
21	A-7E/SDM		50	A-7E/SDM
22	A-7E/MT		51	A-7E/SDM
23	A-7E/SDM		52	A-7E/MT
24	A-7B/MT		53	A-7B/MT
25	P-3C/DLM		54	A-7E/SDM
26	A-7E/SDM		55	A-7E/MT
27	A-7E/MT		56	A-7E/MT
28	A-7B/SDM			

NOTE: (2) INDICATES SECOND AIRCRAFT SCHEDULED ON THAT DAY

Day-Order Schedule Created and Printed by the UNIFORM Program

UNIFORMLY DISTRIBUTED INITIAL SCHEDULE FOR [illegible]
IN TYPE ORDER

AIRCRAFT TYPE	SEQ	DAY
A-7B/MF	1	3
	2	9
	3	14
	4	20
	5	24
	6	31
	7	38
	8	42
	9	48
	10	53
A-7E/MT	1	3
	2	5
	3	6
	4	11
	5	13
	6	16
	7	19
	8	22
	9	27
	10	30
	11	34
	12	36
	13	39
	14	44
	15	45
	16	52
	17	55
	18	56
A-7B/SEM	1	28

AIRCRAFT TYPE	SEQ	DAY
A-7E/[illegible]	1	2
	2	4
	3	7
	4	10
	5	12
	6	15
	7	18
	8	21
	9	23
	10	26
	11	29
	12	32
	13	35
	14	37
	15	40
	16	43
	17	[illegible]
	18	50
	19	[illegible]
	20	54
P-3[illegible]M	1	8
	2	17
P-[illegible]M	1	[illegible]
	2	[illegible]
	3	41
	4	49
ES-2D/R	1	47
RF-3A/[illegible]	1	1
TOTAL		57

Type-Order Schedule Created and Printed by the UNIFORM Program

BIBLIOGRAPHY

1. Bell, T.E., "Graphical Analysis Procedures for Simulation and Scheduling," Doctoral Thesis, University of Calfornia, Los Angeles (1968).

2. Carlson, E.D., Editor, "Proceedings of a Conference on Decision Support Systems," DATA BASE, 8,3 (Winter, 1977).

3. Carlson, Per-Olof, "An Interactive Heuristic Approach for Scheduling a Multi Resource Constrained Problem," Unpublished Master's Thesis, University of Florida (1977).

4. Connor, J.L., "Sequence Programming: A Heuristic for the Solution of Large, General Job Shop Scheduling Problems," Doctoral Thesis, Illinois Institute of Technology (1971).

5. Dannenbring, D.G., "An Evaluation of Flowshop Sequencing Heuristics," MANAGEMENT SCIENCE, 23, 11, 1174-1182 (1977).

6. Davis, E.E., and G.E. Heidorn, "An Algorithm for Optimal Project Scheduling Under Multiple Resource Constraints," MANAGEMENT SCIENCE, 17, 12, B803-B816 (1971).

7. Ferguson, R.L., and Curtis H. Jones, "A Computer Aided Decision System," MANAGEMENT SCIENCE, 15, 10, 550-561 (1969).

8. Godin, V.B., "Interactive Scheduling: Historical Survey and State of the Art," AIIE TRANSACTIONS, 10, 3, 331-337 (1978).

9. -----, "An Interactive Computer System for Production Scheduling," Doctoral Thesis, Graduate School of Business Administration, Harvard University (1969).

10. Godin, V.B., and C.H. Jones, "The Interactive Shop Supervisor," INDUSTRIAL ENGINEERING, 1, 11, 16-22 (1969).

11. Gupta, J.N.D., "Combinatorial Search Algorithms for Scheduling Problem," M. Tech. Thesis, Indian Institute of Technology, Kharagpur, India (1967).

12. -----, "A General Algorithm for the N x M Flowshop Scheduling Problem," INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH, 7, 3, 241-247 (1969).

13. -----, "M-Stage Scheduling Problem, A Critical Appraisal," INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH, 9, 2, 267-281 (1971).

14. Haider, S.W., "An Investigation of the Advantages of Using a Man-Computer Interactive Mode for Scheduling Job Shops," Doctoral Thesis, Purdue University (1969).

15. Hall, D.J., "Man-Machine Projects at SRI," INTERNATIONAL JOURNAL OF MAN-MACHINE STUDIES, 2, 4, 363-394 (1970).

16. Herroelen, W.S., "Resource-Constrained Project Scheduling: The State of the Art," OPERATIONS RESEARCH QUARTERLY, 23, 3, 261-275 (1972).

17. Holloway, C.A., and R.T. Nelson, "An Interactive Program for the Job Shop Scheduling Problem with Due Dates," Stanford University Graduate School of Business, Technical Report Number 22 (1972).

18. -----, "Alternative Formulation of the Job Shop Problem With Due Dates," MANAGEMENT SCIENCE, 20, 1, 65-75 (1973).

19. Jones, C.H., "A Comparative Study of Decision Making From Computer Terminals," AFIPS, Proceedings of the Spring Joint Computer Conference, 599-605 (1970).

20. Licklider, J.C.R., "Man-Computer Symbiosis," IRE TRANSACTIONS ON HUMAN FACTORS IN ELECTRONICS, HFE-1, 1, 4-11 (1960).

21. Manne, A.S., "On the Job-Shop Scheduling Problem," OPERATIONS RESEARCH QUARTERLY, 8, 219-227 (1960).

22. Page, E.S., "An Approach to Scheduling Jobs on Machines," JOURNAL OF THE ROYAL STATISTICAL SOCIETY, Series B, 23, 484-492 (1961).

23. -----, "On the Schedule of Jobs by Computers," THE COMPUTER JOURNAL, 5, 214-221 (1962).

24. Pritsker, A.A.B., and L.J. Waters, "A Zero-One Programming Approach to Scheduling With Limited Resources," The Rand Corporation, RM-5561-PR (Jan, 1968).

25. Pritsker, A.A.B., L.J. Waters, and P.M. Wolfe, "Multiproject Scheduling With Limited Resources: A Zero-One Programming Approach," MANAGEMENT SCIENCE, 16, 1, 93-116 (1969).

26. Tobey, A.R., "Research on Man-Computer Communications for Production Scheduling," Final Report, Stanford Research Institute (1967). (Note: This report is not available to the general public.)

27. Van Duuren, A. and J. Verantvoort, "Job-Shop Scheduling," Proceedings of the Symposium on Interactive Computer Graphics, Delft, Netherlands (Oct 16-17, 1970).

28 Weist, J.D., "Toward a Man-Machine Interactive System for Project Scheduling," Lecture Notes in Economics and Mathematical Systems, No. 86, (symposium on the Theory of Scheduling and Its Applications"), SpringerVerlag, New York (1973).

BIOGRAPHICAL SKETCH

Gerald Wayne McDonald was born at Rifle, Colorado, on July 18, 1932. After dropping out of high school, he joined the navy in 1950 and served therein for over twenty-five years. He rose through the enlisted and commissioned officer grades to the rank of Commander. At retirement he was the Commanding Officer of a three hundred fifty man patrol squadron stationed at Jacksonville, Florida.

During his navy career, Mr. McDonald attended school part-time at St. Mary's Junior College and the University of Maryland's extension program. He received a BS degree in engineering science from the Naval Postgraduate School in December, 1969, and a Master of Science degree in computer systems management from the same institution during June, 1970.

Following retirement from the navy, Mr. McDonald served as Program Coordinator and Instructor in the Department of Data Processing at Jones College, Jacksonville, Florida, before enrolling at the Unversity of Florida.

Mr. McDonald has been a student in the graduate program of the Management Department of the University of Florida since January, 1977. For a minor, he received a Master of Engineering degree in industrial and systems engineering during June, 1979. He received a Graduate Council Fellowship during 77-78, and a Fellowship from the Center for Econometrics and Decision Sciences during 79-80.

Mrs. McDonald is the former V. Lucille Clemons of Piggott, Arkansas. They have three grown children, two daughters, Vickie Lynn and Myra Marie, and a son, Wayne Thomas.

FILM